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AIRLINE SCHEDULE PUNCTUALITY MANAGEMENT

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ABSTRACT

Airline schedule punctuality is a complex problem and one of the major concerns of the airline top management. Flight schedule disturbances may occur as delays and/or cancellations. There are many internal and external reasons for delays. These delays may propagate in the aircraft cycles and cause a large schedule disturbance. This may influence passenger satisfaction and airline resources. The objective of this research is to formulate a systematic approach for schedule punctuality which supports management decision making.

The punctuality management system is structured to combine all schedule punctuality components, input and output variables. Five models are incorporated in this system. The first model is the disturbance model which generates random delays based on an estimated Lognormal delay distribution function. The delay analysis is carried out from a one year sample of delay statistics in which general, original, reactionary and other delay types are classified. The second model is the recovery model which incorporates the disturbance model with management strategies to determine delay propagation. A PC based simulation model (SKDMOD) is developed as a prototype which integrates disturbance and recovery models using SIMSCRIPT II.5. 18 management strategies are simulated covering ground times (30, 40 and 50 minutes), maximum delay times to assign spare aircraft (1, 2, 3, 4, 5, and 6 hours) and spare aircraft using part of the domestic network of Saudi Arabia. The third model is the passengers' attitude model which determines the delay impact functions and the maximum passenger revenue loss based on 262 responses from a passenger interview survey. The fourth model is the revenue model which estimates the passengers' revenue loss. The fifth model is the cost model which estimates the extra cost resulting from implementation of the management strategies. All strategies are evaluated to determine the optimum based on profit and profit margin. OPTIM is the optimization program developed to find the optimum strategy(ies).

This approach provides a guidelines for the management of punctuality. It integrates all the tools developed in a decision support system framework.

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Chapter (1)

AIRLINE SCHEDULE PUNCTUALITY MANAGEMENT

This chapter introduces the dimensions of punctuality management and the impact on airline's operational and financial performances. Section 1.1 introduces a background of airline schedule operations and describes briefly airport activities which might complicate airline punctuality. Section 1.2 gives an overview of airline punctuality management issues. Then section 1.3 discusses the general management strategies to attain a higher punctuality level. Section 1.4 illustrates the internal and external disturbances that impact the punctuality. Section 1.5 discusses the overall objectives of this research and the research scope.

1.1 INTRODUCTION:

In commercial airline operation the flight schedule is a vital and central issue in the airline planning process. "It defines not only the product but to a large extent also the production plan. Given a flight schedule, a significant portion of cost and revenue are fixed. Optimization of flight schedule, therefore, is central to finding the most efficient and effective deployment of an airline's resources. ..." (ETSCHMAIER AND MATHAISEL (1)). The airline scheduling problem is solved through a structured planning process in which all parts of the airline participate i.e. marketing, flight operations, technical, maintenance planning, materials management and civil aviation and airport authorities. A series of meetings take place with representatives from other airlines to discuss the level of operation and schedule for both sides. Much of the flight scheduling can be handled by computers, but many of the crucial decisions and alternatives are made by humans. Systems of this type emerged in the 1960s under the name of schedule development and evaluation systems (BROUGH (2,3), TOBIN AND BUTFIELD (4), LOUGHRAN (5), ETSCHMAIER (6), ELCE (7), AGARD (8), and WALKER-POWELL (9)). Most airlines have a central schedule planning department developing draft schedules which are evaluated by various areas in the airline in terms of its feasibility from marketing and operational viewpoints and in terms of its economics. Based on this evaluation, a new draft schedule is prepared. The iterating process is continued until either convergence is reached or time to develop the schedule plan is expired. " The two phases of this iterating process are referred to as *schedule construction* and *schedule evaluation*."(1).

Schedule construction takes into consideration only factors of primary importance such as : passengers with a simple demand function for each market, an active fleet with its planned level of operation, aircraft operational

characteristics including some simplified cost evaluation, the route structure and the airline network with consideration of corporate goals and other airlines competition.

The approach taken in the schedule construction process can be divided into direct approaches and stepwise ones. The direct approaches use a heuristic procedure for preparing a schedule by sequentially selecting flights and possibly making small changes in flights previously selected. While some old models were entirely computer based (AGIN (10,11), CHAN (12), LARSON(13,14), LEVIN (15-17), BENBASSET (18), SOUMIS (19), SOUMIS et al (20), LOUGHRAN (5)), models currently in use provide a man-machine interactive environment in which the selection of flights is made by the planner (NIEDERER (21), WILLIAMSON (22), KYLE (23), LIU (24)). Stepwise approaches begin by selecting the routes which are to be served and determining the frequency of service on each route. This step is called frequency planning and optimization (DANTZIG (25), KUSHIGE (26), MILLER (27), MATHAISEL (28), MATHAISEL AND DE LAMOTTE (29), RICHARDSON (30). The second step determines departure times based on time-of-the-day variability of demand and flight connections. The third step checks the departure time for operational feasibility. Aircraft rotation plans are developed to find out the number of aircraft required to run the schedule, and changes are identified which could lead to a reduction in the aircraft requirement (LOUGHRAN (5), RICHTER(31,32), TEWINKEL (33), STRUVE (34), LABOMBARDA AND NICOLETTI (35).

Schedule evaluation involves typically the whole airline because some tactical decisions related to schedule implementation are the responsibility of various departments. Evaluation in terms of feasibility and economics includes the determination of the cost of the schedule operation which requires the development of relatively detailed tactical plans for various departments. Some of the factors that are usually considered are precise demand functions, **punctuality inherent in the schedule**, cockpit and cabin crews, ground crews and ground handling facilities, and aircraft maintenance requirements. Evaluation of those factors requires different types of models. For an extensive discussion of these models, refer to (ETSCMAIER AND MATHAISEL (36)).

This research concentrates on schedule evaluation in terms of punctuality, which determines the stability of the planned airline schedule. Execution of an airline schedule amounts to many interdependent and synchronous activities of aircraft, crews, passengers and cargo. Any disturbances in any of these activities will have an impact on flight punctuality. Running the airline schedule operation requires availability of aircraft scheduled for that route, equipment which supports that type of aircraft and people to handle and coordinate all those activities. It is worth mentioning that there are different aircraft ground activities that take place on the ground; each aircraft type has different ground servicing from the rest of the fleet in both turnaround station and through station.

For example **figure (1-1)** below, illustrates the servicing activities required for a B737 aircraft at the turnaround station with 65% load factor and both doors used.

The servicing function is as follows: lower airstairs, provide ground support equipment, deplane passengers, unload baggage, unload cargo, fueling, service waste tanks, service water, service galley, service cabin, perform maintenance checks, then load cargo first, then baggage, then enplane passengers, start engines and request clearance for departures(SAUDIA (71)).

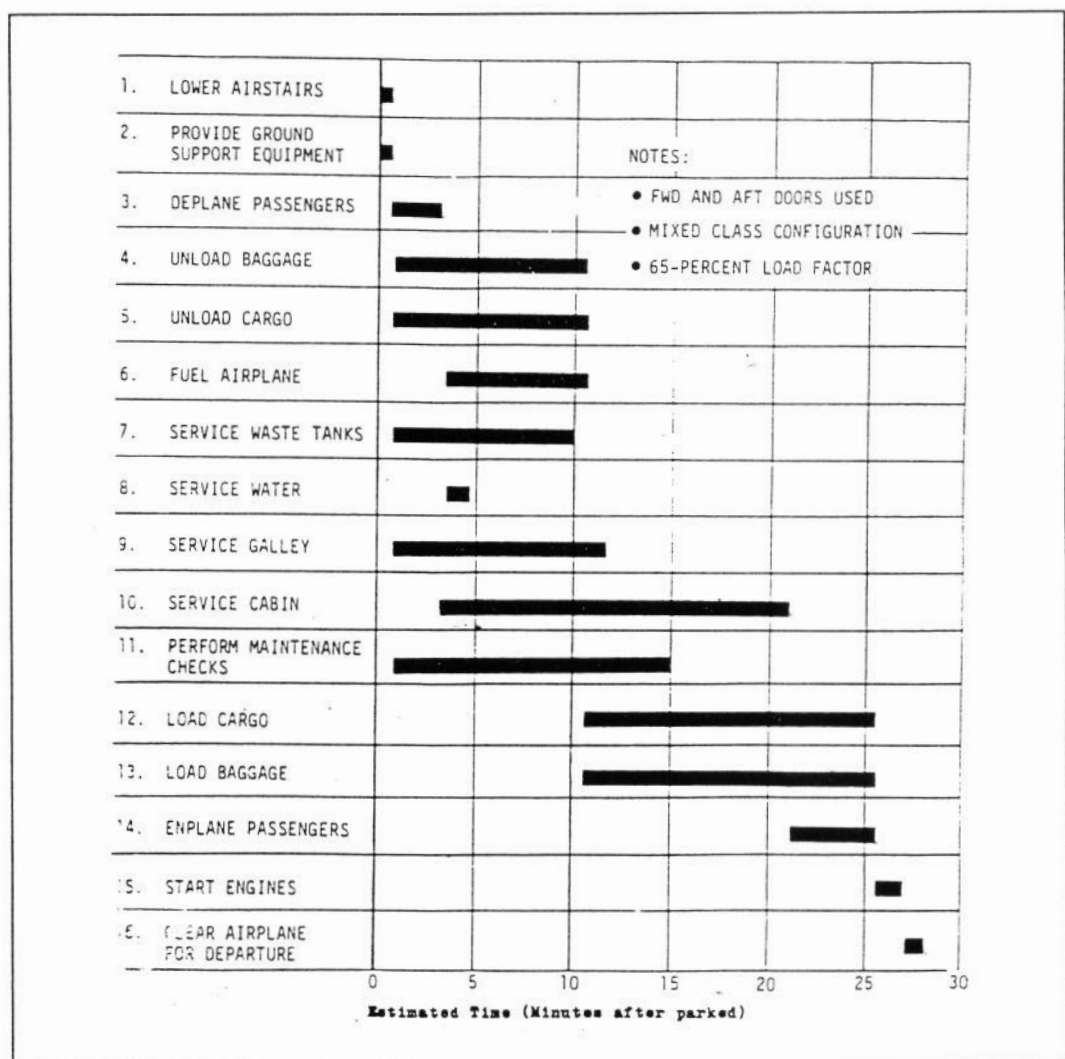


Figure (1-1)

Aircraft Ground Activities

Punctuality Management is one of the major concerns of international and competitor regional airline top management. Many different disturbances happen to airline schedule operations daily. Some disturbances are external and some have internal causes.

Airline management always has a concern about on time performance and their strategies regarding improvement. Considerable effort is expended by airline top management to come up with different strategies to improve the level of schedule punctuality. One of the major Saudia's corporate objective, as stated in the five year plan 1985-1990, is to increase or keep the current market share through offering good services and gaining high reputation. One of the tactics for this objectives is schedule punctuality (SAUDIA (47)).

1.2 Overview of Punctuality Management Issues:

Airlines try to be punctual especially on their scheduled operations, but in many cases airlines fail to be on time. The unpunctuality has a number of dimensions which concern the airline management and passengers. They vary according to the severity and frequency of schedule disturbances; delay or cancellation.

- a) **Passenger inconvenience** is one of the major problem areas that an airline might experience. Most of schedule feasibility studies from a marketing point of view concentrate on the best arrival and departure times for the flights. Most if not all these studies are based on commercial considerations especially if the airline is a commercial or private airline.

The inconvenience comes from different aspects; a business passenger booked on 12:00 flight from Jeddah to Dhahran, with expected arrival time of 14:00, is engaged in a busy business schedule to sign a business agreement with oil company in Dhahran at 15:00 hours. For some reason the flight is delayed in Jeddah for two hours, the actual arrival time at Dhahran is 16:00. This business passenger has lost his chance of getting into Dhahran at the right time. This delay might be for technical or marketing or security reasons but in any case it affects this passenger. Passengers who are involved with pre-set schedule of business or medical or social appointments suffer a greater impact in case of disturbances, but passengers without appointments have much less impact. Degrees of passenger dissatisfaction depending on the length and type of disturbance.

Passenger satisfaction is very important to the airline. The importance varies according to the airline objectives for passenger services.

In this research a passenger survey will be carried out to determine passenger attitudes with respect to punctuality, and the level of impact of different disturbances for both business and vacation passengers.

- b) **Aircraft rotation** plans are a graphical representation of flight schedule similar to a GANTT chart. Aircraft rotation plans show the final operational flight schedule for each aircraft tail number of the operational fleet. These plans are used for displaying aircraft status and location at any time in the day or in the week according to the schedule development period. In the case of any disturbance occurrence aircraft rotation plans are consulted to identify the best alternative action to continue the operation as punctual as possible. Some of these modifications in rotation plans are minor which will have minimum impact on these plans and some are significant especially when there is diversion of equipment to another flight .

The degree of disturbance of the aircraft rotation plans depends on the planned aircraft utilization in the schedule. If the schedule is crowded and aircraft utilization is high then schedule disturbance will be high and vice versa. This is due to the disturbance in the individual cycles of that aircraft rotation plan. This disturbance will seriously affect the punctuality. Appendix (c) shows a sample of an aircraft rotation plan.

- c) **Operational constraints** are considered significantly when dealing with flight disturbances especially in the selected flight and station in the network. The following are some examples of operational constraints such as *time slots* obtained in the period of schedule planning from foreign airport authorities. One of the objectives of time slots is to arrange arrival/departure of international flights and consequently decrease possible congestion problems at airport. The number of time slots available in any given period is based upon whatever limiting factors apply at the particular airport - runway movement rate, aircraft parking capability, passenger handling inside the terminal, etc. YATES (69)

Congestion is a normal outcome in busy airports and it gets worse if airlines are not operating according to the plans. "In practice , we find some 20% of carriers that their long haul early morning arrivals into Sydney are more than one hour late. This is partially due to the congestion they all experience en route, partly due to sharply differing passenger loads, partially due to seasonal wind variations and of course, partly the results of mechanical, operational and weather delays." YATES (69). More people and more aircraft lead to more delays, JAMES (46) shows this trend in the USA airports and argues that in the longer term there must be more spending on the infrastructure if re-regulation is to be avoided while in the short term temporary measures may alleviate the growing air traffic congestion.

"Air Transport Association studies in the USA have shown that delays due to movement limitations increased *aircraft operating cost* to the

industry by about 1.2 billion US dollars, plus another 800 million dollars for gate space and personnel to cope with the unfortunate passengers - this is about four percent of airline revenues, and exceeds the total airline industry profits in a single year!".(70)

Flight cockpit and cabin crews schedules are developed based on the airline flight schedule plan. Future crew schedule plans are disturbed especially in case of large delays or cancellations. This constraint is important for legal reasons because the pilot is allowed from Federal Aviation Authorities or from Civil Aviation Board to fly a maximum number of block hours during different stages for safety purposes. If this limit is exceeded at any stage then the airline might run into legal problem.

Curfews where certain airports in the network have limited operating hours also is an example of an operational constraint that is normally considered when dealing with delays. The situation is further compounded by the existence of night curfews at many airports, for example London, Paris, Amsterdam, Frankfurt, Hong Kong, Sydney and Tokyo.

- d) **Resource utilization** is carefully planned when developing the flight schedules. Utilization might be influenced by schedule disruptions in some cases. When an aircraft has a technical delay it will be held on the ground for the maintenance period. This will lead to lower *aircraft utilization*. Other resources such as *manpower crews* in different areas; maintenance, engineering, marketing are influenced. Also, ground handling equipment and terminal gates will be influenced.
- e) **Aircraft maintenance plans**; each aircraft has a maintenance plan consisting of different checks, which in all cases are functions of number of block hours flown. This plan will be disturbed too because modification in rotation plans will change the cumulative number of block hours for each aircraft.

1.3 MANAGEMENT STRATEGIES:

Punctuality can be managed better and the level of performance can be improved by adopting different strategies depending upon the severity of the schedule disturbances. These strategies can be categorized into three types of management strategies. *Planning strategies, operational strategies and supportive strategies*. The following are examples of possible strategies that management can practice and some of them are used in airlines but not only in the context of punctuality management:

- a) Providing more *slack time* in flight duration to be considered as a buffer

is one of the planning strategies. The planned flight duration has both the expected block time plus the slack time. All scheduling activities are using the flight duration with the proposed slack time and it will be published in the airline timetable accordingly. Normally passengers do not notice it, but they will appreciate either arrival ahead of planned time if there was no delays, or smaller delay if there was a delay. On the other hand due to slack time the airline suffers from lower utilization of aircraft, cockpit and cabin crews and other ground facilities. This low utilization cannot be improved because aircraft, crews and other equipment are engaged and they are considered as active resources.

- b) Provide the facilities for easy *aircraft diversion* into different cycles different from the planned cycle. This strategy is an example of operational strategies which normally increase airline operational cost. In this case aircraft rotation plans are usually consulted to determine the flight operation feasibility of aircraft diversion of the same aircraft type or different configuration depends on the availability of the fleet at that time.
- c) Increasing *ground crews* in case of shortage or improving their skills by more target training and on the job training. Ground crews refer here to all working groups on the airport ground aiming to serve the aircraft. Technical, traffic control, catering, departure control, ramp services, general airport services are examples of manpower in the airport. This strategy is an example of supportive strategies which affect punctuality.
- d) Provisioning of additional *spare aircraft* to the airline fleet which can be used when scheduled aircraft are unavailable.
- e) Improving the preventive maintenance procedure and ways to control its implementation.
- f) Implementing of award program to enhance employee and station performance. This is an *incentive* which can be adopted through different award policies and approaches, i.e. the best rated on time performance station in both domestic and international network or the best employee in the division, etc..

All of the previous mentioned strategies are subject to management influence. These strategies have an effect on airline operational costs and may influence passengers satisfaction which in turn may affect airline revenue. So airline top management needs a systematic management approach to optimize schedule punctuality.

1.4 PUNCTUALITY DISTURBANCES:

Having overviewed issues of punctuality management and management strategies that can be adopted, let us discuss causes of delays and disturbances. Most of punctuality disturbances are classified into two classes; the first class is disturbances due to *internal factors* such as aircraft, equipment, crews, etc. and the second class is due to *external factors* such as weather, government authorities, security, etc.

Both internal and external disturbances can generate a flight delay or flight cancellation. Delays are defined and classified in Appendix (A). Also appendix (A) demonstrates the method of calculating these delays with some examples in Saudia. Delays classifications might be different in other airlines.

The following are the different categories of delay codes which are classified according to the departmental responsibilities and for airline use. The category is defined here as a group of pre classified individual delay codes. This classification, as below, is summarized from the Saudia Marketing and Ground Manual as used in actual delay allocation and for on-time performance analysis. Most probably this delay classification is general and applicable to other airlines except in specific cases.

- 1) *Airline internal use* is a delay category involving equipment shortage, reactionary delays and late arrival delays due to previous marketing, material, maintenance, automation system, flight operations, weather, airport authority or airport closure reasons.
- 2) *Marketing delays* are categorized to include all delays from different areas of passenger, baggage, aircraft handling and ramp handling. This classification suits Saudia organization because all the above departments report to the EVP Marketing. Examples of passenger and baggage delays are late check-in, check-in error, over sales booking errors, boarding, connections, baggage handling, catering orders; cargo delays can be due to errors in documentation, late positioning of cargo, inadequate packing.
- 3) *Aircraft and ramp handling* delays involve aircraft documentation, loading and unloading equipments, aircraft cleaning, catering, cabin crew shortage or late boarding, security, immigration and health.
- 4) *Technical and aircraft movement* delays are many including aircraft defects, lack or breakdown of maintenance and servicing equipments, delay in scheduled maintenance, non-scheduled maintenance, aircraft change, standby aircraft, personnel, maintenance routing and airport facilities i.e. parking stands, ramp congestion, lighting, buildings, gate

limitations, mobile lounge.

- 5) *Material management* delays are fueling/defueling, lack of spare parts, personnel errors or damage, aircraft on ground (AOG) spares which have to be carried to another station.
- 6) *System delays* are due to failure in automated equipment and systems i.e. departure control system, cargo preparation, flight plan and other systems.
- 7) *Flight operations* have many delays types such as completion of flight plan, extra operational requirement, late flight deck crew boarding or departure procedures, flight deck crew special request, late flight deck crew boarding or departure procedures, personnel, air traffic services clearance, including ATC and movement control.
- 9) *Airport and government authorities* include delays due to incorrect mail documentation, late positioning of mail, late acceptance of mail, restrictions, airport closed, security including special flights, airport closed for VIP movement, no gate or stand available due to own airline activity and etc.

1.5 OBJECTIVE OF THIS RESEARCH:

The objective of this research is to formulate a systematic approach to support airline management in decision making for schedule punctuality considering all of the above mentioned punctuality management issues and possible management strategies. In this research emphasis will be on the evaluation strategies covering *schedule planning* and major airline internal factors influencing punctuality.

The following major sub objectives are formulated to provide management with the required decision support system:

Formulation of the structure of punctuality management system. This formulation includes the description of the entire system's model and components.

Classification of aircraft schedule disturbances including delays and cancellations. Determination of general delay frequency and delay time distribution functions from a statistical analysis of the historical delay data. Measurement of the original delay distribution function and the reactionary delay function which results from the propagation of the original delay in the schedule.

In depth analysis of each type of delay including general, original, and reactionary by different category of delay i.e. marketing delays, technical delays, operational delays, etc.. More in depth analysis by aircraft type, region where delay occurs, and by month in order to discover variation in the delay functions.

Estimation of these delay functions including general, original and reactionary into synthetic distribution functions such as Lognormal and Weibull.

Measurement of passengers attitude towards schedule punctuality by conducting a passenger interview survey at the domestic and international departure lounges. Estimation of passengers impact functions and revenue loss functions for both business and vacationers.

Development of schedule simulation prototype model in which the planned aircraft schedule will be simulated using different management strategies. A PC based interactive simulation model is developed using PC Simscript II.5. The simulation concentrates on the evaluation of management decisions covering slack times in flight block time including the aircraft ground times and number of spare aircraft. These are examples of the planning strategies. Maximum delay time to assign a spare aircraft (MDAS) is a third type of management strategy that is used in this simulation model. MDAS is one of the operational strategies. The schedule simulation model contains two major processes one for aircraft assignment in which the system assigns aircraft to flight and the second major process is the scheduling process where a delay function is inserted.

Optimization analysis of each management strategy in terms of the trade off between passengers convenience and extra operating cost incurred. Formulation of optimization formula enable one to determine the best strategy to follow based on a decision criteria. Also, sensitivity analysis of major airline parameters is performed to demonstrates a more global vision of punctuality management.

1.6 **PREVIOUS WORK:**

Operations research groups in some airlines have spend a great deal of effort in the development of simulation models which will help keeping better punctuality levels. A major difficulty lies in the analysis and modeling of the dependencies of the random events in the schedule.

Previous work was greatly simplified due to different reasons one of these was the unavailability of systematic methods for gathering reliability data. Some simulation models ignore weather disturbances and other have major assumptions in aircraft assignments. All of the previous simulation models are classified into two groups; the first group consider the aircraft assignment in

the schedule is predetermined and fixed. Because it represents aircraft cycles or rotations the simulation is called *Cycle Simulations*. The second group assumes no prior assignment has been given to flights and during flight dispatch the aircraft assignments will be given according to the situation. This is called *Aircraft Assignment Simulations*.

Most of the old models are aircraft assignment simulation models; the first was by Air France (DEQUESNOY (37)), the second by Air Canada (LEE AND FEARNLEY (38)) and the third by BEA (JACKSON AND SMITH (39)). The following quote is a comment about those models from ETSCHMAIER AND ROTHSTEIN (40); "These models are reasonably successful in so far as they reproduced fairly accurately the pattern of delays in the schedule. They were used for making important decisions, mainly concerns the availability of spare aircraft, no persistent pattern of routine use in the schedule development process evolved". The main reasons for such complications as mentioned in Etschmaier's paper are due to data collection for each simulation run, long CPU time and difficulties in drawing conclusions from the simulation results.

Tobin and Butfield of BEA (41) improved the cycle simulation model by working more on the databases and the routine data collection system, as well as the compatibility of using simulation model with extracts of the schedule. British Airways used this model whilst the stability of the planned cycles were investigated to determine the number of standby aircraft needed when swapping with unserviceable aircraft.

In 1975 British Airways subsequently evolved the planning process to on line computer scheduling without a reference to cycles. "The aircraft cycle simulation became infrequently used for three reasons:

1. The necessary process of cyclisation was inconvenient and the simulation's answers were dependent on these derived cycles.
2. The simulation was too time consuming for running on line so that the results could not be obtained as the schedule changes were proposed. An on line version which would test a single cycle typed in the terminal was still slow and awkward to use.
3. Elaborate outputs, intended for detailed analysis of cycles, seemed to be too complicated so that it was difficult for a scheduler to grasp the weak areas and decide on sensible corrective action.

... "a need became apparent to derive the set of cycles of schedule at a time close to operations".

WILSON (42) developed the cycle simulation model to cope with the on line

scheduling process that exists in BA. The model has been used since 1975 which results in using the simulation model more regularly by schedule planners at the schedule planning process. British Airways Standby Simulation (BASS) (43) is used currently to simulate all possible delays and unserviceabilities for a fleet on a day's or a week's schedule and it provides various punctuality estimates. This system is beneficial for aircraft standby analysis.

Another comprehensive work in cycle simulation was done by FRANKE (44) of Lufthansa airline. He considered the schedule as a set of dependent and independent random variables which affect block time and some will affect ground time. A mathematical equation of block time is derived with seasonality and time of day variations allowed in the equation, but Franke used a greatly simplified model for ground time due to lack of detail of on ground delay data.

The model of schedule punctuality can be carried out numerically or by simulation. In the numerical approach all variables are quantified based on mathematical equations and the solution is found by analysis of these equations. Simulation determines the output by simulating the actual operation of the schedule over a period (e.g. day) using random variables. Franke (44) and Bindler (45) used a numerical approach to solve their models. Franke also used a simulation approach using GASP II which is a set of FORTRAN subroutines. Franke had a couple of observations regarding using the numerical approach; although computer run time is comparable, memory storage requirement is considerably higher than simulation. The second observation is the relative rigidity of the programs. According to Franke a small change in the structure of the model leads to a large amount of changes in the programs. The latter observation could be overcome by carefully designing the program logic in a structured way which allows later changes and developments.

By means of the state of the art in simulation systems the schedule simulation programs can be written very efficiently and interactively. Such systems as SIMSCRIPT or SIMULA or GPSS etc.

The above mentioned models and studies focus only on solving a management problem such as determination of required number of spare aircraft and schedule delays. On the other hand this research focuses on the whole schedule punctuality management including the decision making process and simulation of management strategies for schedule punctuality. So a schedule simulation prototype model will be developed using a *simplified* delay model to demonstrate ways of support to airline management in the schedule punctuality decision making.

Chapter 2

STRUCTURE OF PUNCTUALITY MANAGEMENT PROBLEM

As described in Chapter 1 "Introduction to Punctuality Management", passengers inconvenience and airline resources have a great effect on traffic demand and on airline operational conditions. Airline resources include aircraft, handling and support equipment, human crews in operations and marketing, airline operational plans. Examples of plans are schedule plans, cockpit and cabin crews plans, maintenance plans and ground crews.

The purpose of this chapter is to formulate and explain the overall system structure of punctuality management. First a description of the complexity of this problem and the possible conflicts arising between management decisions and corporate objectives are illustrated in section 2.1. An analysis of the punctuality management system including the overall system structure, system components, environmental and world effects are shown in section 2.2. This analysis includes some definitions and concepts of systems, system's components, and airline / world environmental impact. Section 2.3 discusses the formulation of the punctuality management system structure including the major system inputs, outputs variables and an explanation of a schematic structure of the punctuality management system with models involved. Section 2.4 demonstrates the possible mathematical and conceptual formulations of the system models discussed in the previous section. Section 2.5 introduces the basis of a systematic method for punctuality management on a regular basis. A type of Decision Support System (DSS) approach is also proposed and discussed as an alternative approach to the conventional approach used to obtain required information.

2.1 INTRODUCTION:

Various management strategies were presented briefly in chapter 1 such as provision of more slack time in either flight block time or in aircraft ground time, provide additional spare aircraft, improve level of component reliability, prepare flexible aircraft rotation and diversion plans and increase quantity and quality of operational and marketing crews.

Obviously, the implementation of these strategies is going to affect the airline's operating cost and affect the operating revenues. For example, if an airline has a low punctuality performance then its management has decided to implement a strategy which will keep one or two aircraft as spare aircraft then the airline will need more aircraft to cater for its services and consequently this will increase the operating cost (maybe in this case only the fixed cost). On the other hand, this will be more advantageous in implementing one of the strategies "prepare flexible aircraft rotation plans...".

In this case both strategies will keep the level of punctuality high and perceptively passenger's satisfaction is also maintained high which has a positive impact on the airline operating revenues. This example shows that the spare aircraft strategy supports the other strategy but at the same time it contradicts with the corporate objectives if cost minimization is the major corporate objective and passengers satisfaction is the minor corporate objective.

Punctuality Management Complexity lies in the possible conflict arising between management strategies, airline corporate objectives, organizational structure and other environmental and system conditions and constraints.

Considering those different management strategies and their dimensions, it requires a great deal of application of management functions such as planning and coordination. The importance lies in identifying the global importance of punctuality and assisting the airline management to set a target level of punctuality which goes along with the corporate objectives. Coordination is vital which helps all the related working groups to meet the punctuality target with its association to corporate objectives.

a) Planning:

Punctuality is planned in the corporation as a corporate policy. The highly successful punctuality management requires an organization which considers the punctuality as part of the corporate policy and the top management gives high attention to the punctuality.

Similar to reliability management, "A really effective reliability department can exist only in an organization where the achievement of high reliability is recognized as a part of the corporate strategy, and is given top management attention. If these conditions are not fulfilled, and if it receives only lip service, reliability effort will cut back whenever cost or time pressure arise. ... It is significant that in Japan the government has made quality a national objective." (48).

The planned policy of punctuality is set by top management. A possible example of the corporate policy is to define a targeted on-time performance of 90%. In most of the airlines the issue of determining the overall economics of punctuality policy is very difficult to measure. In practice, achieving this corporate objective requires the support of all the concerned departments, i.e. operations, technical, material management and marketing (departure control, catering and ground handling and services).

b) Coordination:

Airline target punctuality is determinable if full coordination of the working groups is achieved. Coordination includes the overlapping and the dependent activities among technical, material management, operations and marketing groups. It focuses on the utilization of corporate resources and target punctuality. When technical crews check the aircraft and fix any defects in the allowable check time and material management furnishes the technicians with the spare parts which are required, only then can the flight be punctual.

In case of Saudia, the airline have set up a coordination group located at the airport called FIC - "Flight Information Coordination" which is responsible for coordination between all the working groups trying to avoid any unpunctuality and passenger dissatisfaction. FIC works closely with flight dispatch and planning, maintenance, passenger control, reservation control, airport authorities "air traffic control" and catering.

Practically there is a conflict between the management decisions and the impact of these decisions on the airline corporate objectives. Because normally, all management responses are revenue and cost related so there is a need for a systematic approach that can be adopted and used frequently. This approach can help management to measure the punctuality level and its effect on cost and revenue, and estimate the reactions to their decisions on punctuality level and airline operating revenue and operating cost.

In train services punctuality, the decision making process is also complex to manage. " Decision making about punctuality requires an understanding of the links between failures, en route delays, punctuality, late passenger arrivals and revenue effects. This is a complex task and has been the focus for considerable effort by the Cranfield team." (BLACK et al (52)).

In the next section, a systems approach to the punctuality management problem with a description of its basic concepts, components and impact of the system and world environment on the overall system is introduced.

2.2 PUNCTUALITY MANAGEMENT SYSTEM ANALYSIS:

This section illustrates the systems analysis of airline schedule punctuality management. First the background to the concepts of systems including traditional system definition, system characteristics, system structure and components is briefly given.

Then in the following sub-sections, the punctuality management system is analyzed with a discussion of its characteristics. The characteristics involve purpose, components and environment of the system.

The punctuality management system structure is discussed and formulated in more detail in section 2.3.

2.2.1 Background:

Punctuality management is an engineering and management type of problem and the system's nature of such a problem lies in the characteristics of its components.

A system can be defined as a collection of components, connected by various types of interactions or relationships which collectively respond to a stimulus or demand and fulfill some specific purpose or function (MEREDITH (49)).

Similar definition by BLANCHARD that a system is an assemblage or combination of elements or parts forming a complex or unitary whole such as a river system or a transportation system; ; a coordinated body of methods or a complex scheme or plan of procedures, such as a system of organization and management; any regular or special method or plan procedure, such as a system of marketing , numbering or measuring. Not every set of items, facts, methods, or procedures is a system. A random group of items lying on a table would constitute a set with definite relationships between the items; but they would not qualify as a system because of the absence of unity, functional relationship, and useful purpose (BLANCHARD AND FABRYCKY (50)).

In a system, each component responds to stimulation according to its intrinsic nature, but the actual stimulation it receives and its subsequent actual behaviour is conditioned by the presence and interaction of other system components. Accordingly, the loads or demands placed on a system call into play the individual behaviour of the system components. The system response to applied loads and demands develops from the synthesized composite behavior of that individual component. The following characteristic have to be identified when dealing with a system (MEREDITH (49)) :

System Purpose: there must be a specific purpose of functions that must be, or are being fulfilled or performed.

System Components: there are number of components that can be identified as necessary ingredients or fundamental parts of the system. Furthermore, each component has a variety of attributes that implicitly, physically and behaviourally are necessary for its effective descriptions.

System Structure: these components are inter-related in a manner of satisfying interface consistency between components.

System Constraints/Environments: in the system environment there are constraints that are restricted to the system's behaviour and the individual components response. The source of these constraints vary, some from system's environment and some from the world or industry environment.

2.2.2 Punctuality Management System Purpose:

The purpose of a punctuality management system is to demonstrate the complexity of airline schedule punctuality management and to develop a systematic approach to evaluate and support management decisions and strategies. In other words, to assist decision makers to take the best strategy(ies) that meet the corporate objectives and fulfill airline requirements.

2.2.3 Punctuality Management System Components:

(a) Passenger:

Passenger and cargo are the users of airline services. Normally cargo is shipped for a passenger or for a company which in both cases are considered as customers. Different types of passengers have a different valuation of punctuality. Punctuality to business travellers is critical in some cases where a pre-set meeting or a connecting flight is booked upon his arrival. Practically flight delays exist in airlines but the severity and frequency of delays may influence a passenger's airline selection in future flights.

In case of the occurrence of flight delays, an airline can provide means of communications, transportation, accommodations such as phones, food, beverages, reading materials, mother care room, reducing the impact of unpunctuality on passengers.

(b) Aircraft:

Aircraft are another set of component of the punctuality management system. Aircraft have two elements, the number of *aircraft units* active and spare in the schedule operations and the *aircraft average daily utilization* which both have direct impact on punctuality system.

There is a relationship between aircraft units and aircraft utilization which implies that for more aircraft units there will be less aircraft utilization. A low level of aircraft utilization gives more flexibility while operating the schedule and making changes to the rotation plans. Consequently this will improve the punctuality levels. On the other side highly utilized aircraft make it very difficult to maintain high punctuality levels. Having more aircraft units decreases the aircraft utilization but it improves schedule punctuality.

(c) Schedule:

When schedule plan are developed, many marketing, technical and operational issues are considered. Setting aircraft *ground times* for through or for turn around flights is one of the major elements in aircraft rotation planning. Ground time is left in the aircraft cycles to perform all the required airport and ground handling.

This means if a flight schedule has a short ground time and the aircraft has a busy rotation plan (cycle), then the level of punctuality of this schedule is negatively affected and it will be very difficult to manage it.

(d) Crews:

All the necessary coordination is done by people who are members of different operational, maintenance and marketing crews. Operational crews are cockpit crews and cabin crews, maintenance crews; marketing crews are traffic ramp and control. Investment on crews can be huge either by increasing the quantity and/or the quality of the people working in these crews or by supporting crews with more up to date automated equipment.

(e) Reliability:

Airline operations involve a lot of mechanical and electrical equipment; aircraft maintenance equipment, ground handling equipment, etc.

The reliability of these equipment is vital for punctuality management. There are different ways to maintain higher reliability standards by improving or providing maintenance handbooks and procedures, adopt preventative maintenance programs and establish ways to monitor and control the equipments reliability.

2.2.4 Punctuality Management System Environment:

The system would normally be considered conceptually as being that part of the universe in which interest lays. There would be interaction between the system and certain parts of the surroundings known as the environment (SCHWARZENBACH AND GILL (51)).

The environment around the system has a significant influence on the behaviour of the system. Management objectives, corporate policy and organization are some examples of system environment. Discussion of the punctuality management system environment now will give an overall understanding of the system complexity and help formulate the system.

a) **Management Objectives:**

Airline management *objectives* strongly affect the airline operations and performance because all human, capital and financial resources are geared towards the corporate objectives. Punctuality management is one of the issues in airlines which involves human and equipment management.

Punctuality management objectives vary from one airline to another. If the airline objective is to improve or maximize the level of passenger satisfaction so one of the strategies might be to improve the level of punctuality performance. Passenger satisfaction or generally punctuality management influence the airline passenger revenue and operating cost. Passenger satisfaction can also be influenced through different ways, i.e., offer beverages, food and phone services for passengers to arrange for their hotel or flight connect reservations, re-plan their transportation, child care by providing mother room filled with necessary baby care facilities.

In this study the objective is to maximize the profit of the airline schedule which is the difference between total operating revenue minus total operating cost. So if management objective is profit maximization, then different management responses have to be considered in all of the punctuality management components. Examples of such responses are to provide more communication and services to passengers, provide more spare aircraft, plan a more relaxed schedule, plan a flexible plans in crew scheduling and maintenance plans or improve reliability standards in aircraft and support equipment.

b) **Organizational Structure:**

"Because of several different activities which contribute to the level of reliability of a product, it is difficult to be categorical about the optimum organization which ensures effective management of reliability" (O'CONNER AND PATRICK(48)).

Punctuality management includes aircraft and equipment reliability, airline operational requirements, schedule plans and airline economics. Generally speaking, different management organization structures have an effect on the management of punctuality and it could be considered as another factor of the system environment.

The responsibility for punctuality in an organization has to be responsive to all of the above functions and have authority to control them.

Organization structure is linked with management objectives and corporate policy. If punctuality becomes one of the management objectives then a corporate policy has to be established in order to fulfill this objective. The policy will indicate the scope of the responsibility and areas that are authorized. This area might exist in the organization structure or a new group may need to be established to be responsible for the punctuality management task.

2.2.5 Punctuality Management World Environment:

There are some external factors influencing punctuality management which in its turn influences aircraft manufacturers. Competition among airlines might influence punctuality management. Airline deregulation and globalization, aircraft manufacturers reliability standards are examples of the external environmental factors affecting punctuality management environment.

Standards of aircraft manufacturer engineering, equipment reliability and aircraft design are a major concern of most of the airlines. Theoretically speaking there is an optimum expenditure on reliability in relation to its subsequent benefits. "Equipment reliability is affected by design, development, production, quality control of sub-contractors and maintenance" (O'CONNER AND PATRICK(48)). All the elements mentioned are under the aircraft manufacture control except maintenance which is partly under the airline control.

2.3 PUNCTUALITY MANAGEMENT SYSTEM FORMULATION:

The previous section described the basic punctuality management system analysis including system concepts, components and internal and external environmental factors. This section discusses the punctuality management problem structure. First, the relationships between input and output variables are explored and the major decision variables in the system derived. Then the overall punctuality management system structure is built and discussed. Models in the system structure will be discussed later in the next section.

In the following three sub-sections analysis of the major input variables are discussed i.e. aircraft, crews, equipment reliability and schedule slack times including block time and ground time. Then it is followed by the major output variables such as operating cost, operating revenue and punctuality management performance. Also conceptually, the overall relationships between input variables and output variables are discussed.

2.3.1 Input Variables:

(a) **Aircraft:**

Aircraft including the number of operational aircraft units and its performance capabilities is one of the major elements which have a direct link on punctuality.

Aircraft have a maximum limit on daily utilization, because practically speaking, some hours are used as flying block hours, some as maintenance and some as ground time for through or turn-around flights. This time boundaries will affect the utilization.

As discussed earlier for more aircraft units operating in the schedule a given average daily aircraft utilization will be lower.

The other side of having a fleet with low utilization is the cost of maintaining a large fleet in good working condition. Even aircraft on ground need maintenance checks to be ready for flying. In addition to the spare parts which have to be provided in store houses according to the fleet size. This will definitely increase the airline total operating cost.

There is another relationship between punctuality and operating revenue. As the airline has high punctuality levels and passengers have the same high reputation about the airline, then passengers will continue using that airline thus there is a probability of growth in passenger revenue. otherwise passenger revenue will not be affected. Similar relationship exists for low punctuality and passenger revenue. As punctuality levels decrease some of the passengers will be impacted by the low punctuality performance and consequently passenger revenue will also be decreased. It is difficult to demonstrate this relationship in absolute values now but later in this thesis the passengers attitude is measured.

Summary of Aircraft Relationship:

For more aircraft, assuming similar required operational hours, the less aircraft average utilization will be. Low aircraft utilization factors leads to high punctuality and on the other side it will lead to high operating cost. High punctuality keeps and / or generates more passengers revenue. **Figure (2-1)** shows this relationship:

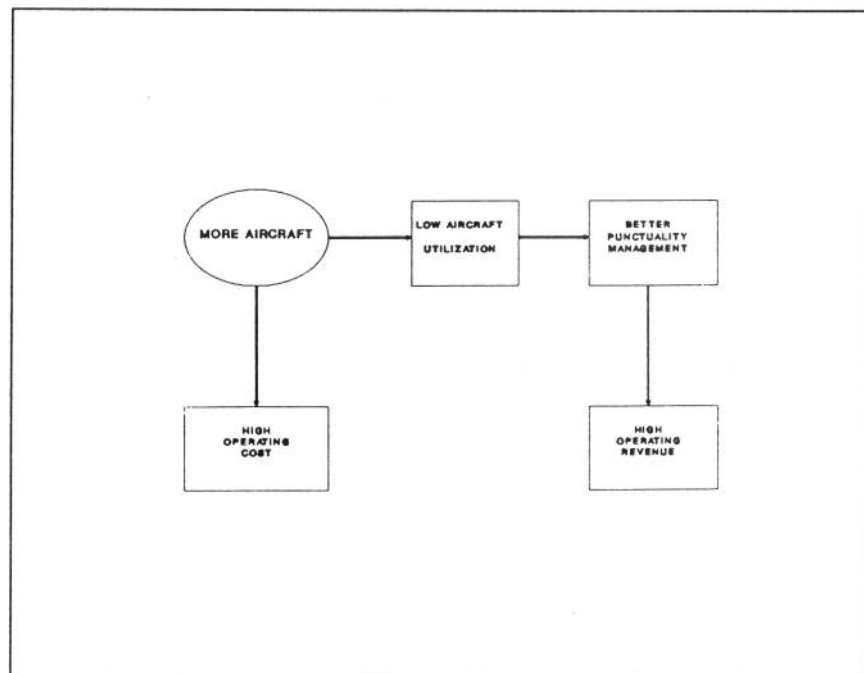


Figure 2-1 Aircraft

(b) Crews:

Crews involve all types of operational, technical and marketing crews as mentioned earlier. When looking at crews as an element to improve punctuality management, either increase the quantity of the people working in these groups in case of shortage and / or improve the quality of those people. The improvement of quality can be studied more from different points of views such as high technical training in overall dimensions of the airline and aircraft industry. Other views such as adopting the strategy of on-the-job-training supervised by highly skilled technical experts.

Figure (2-2) shows this relationship where more quantity or quality of crews leads to higher punctuality performance but on the other hand it will increase the airline operating cost. An improvement in punctuality performance will result if the causes of disturbance were due to personnel. More punctuality leads to high passenger revenue.

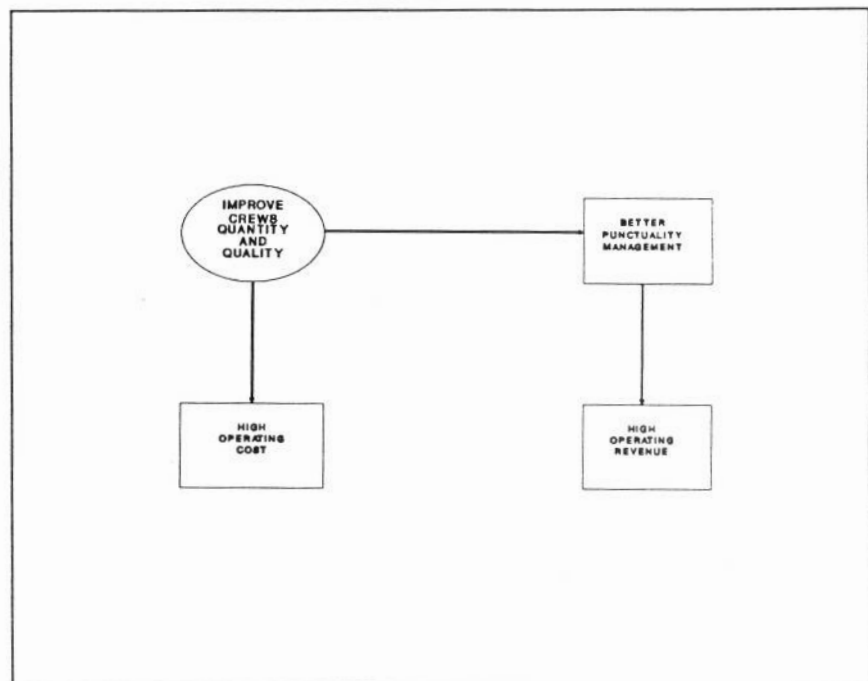


Figure 2-2 Crews

(c) **Reliability:**

Reliability of aircraft and supporting equipments is very critical for punctuality. Adopting more reliability programs and achieving high standard enhance the punctuality performance because aircraft and equipment are always available in working condition. Maintaining reliability standards is very expensive to the airline and there is no clear cut to the optimum level of reliability. For higher reliability levels an airline will have more operating cost and more reliable equipment.

High punctuality performance keeps or increases the operating revenue as shown in **figure (2-3)**:

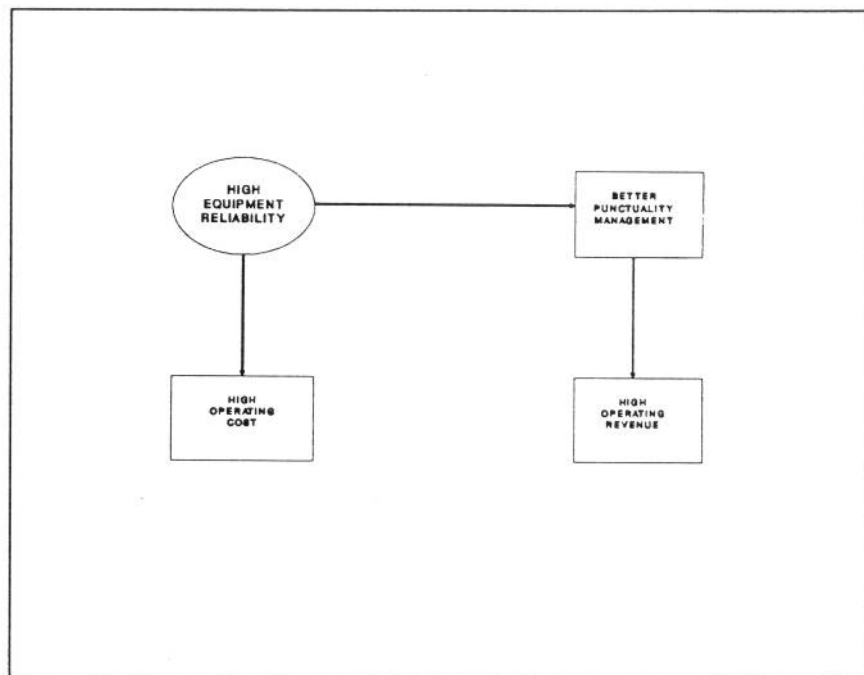


Figure 2-3 Reliability

(d) **Schedule:**

Schedule is the internal element that airline can control to achieve different utilization factors and consequently better punctuality levels. Here schedule is the process of schedule planning where the schedule planners can provide slack times in flight block times. These slack times are used as a buffer when flight departure is disturbed.

Schedule Variables:

The major schedule variables are *slack time and aircraft utilization*. Slack time can be used for aircraft ground time, and flight block time. Slack time is the extra time that is inserted in flight block time between each city-pair or segment. Aircraft ground time for through or turn-around station is the time an aircraft is held on ground for operational requirement. Ground times differ among international and domestic flights, narrow and wide body aircraft and also differ among different airports. Slack time in ground time is the extra time reserved for irregularity during ground activities. The second variables in schedule plan is the *Utilization factor*. Actually it is a by-product; it is a dependent factor on number of operational fleet so it is considered here as a performance measure.

Slack Time:

Ground time is the time between arrival and departure of the aircraft for through and turn around flights. In the schedule construction or evaluation the aircraft are marked busy at these intervals of times. Schedule planners and maintenance planners always determine ground times for both through flights and turn-around flights.

Each aircraft has different ground times based on the ground activities that have to take place. A Boeing 737 will have less ground time than a Boeing 747 and similarly with Airbus and Tristar. In some stations the same aircraft need more ground time than other stations because of the availability of ground handling equipments or ground crews. These constraints can be handled as scheduling constraints when planning a schedule and that possible changes in aircraft cycle might remove the necessity of increasing ground time. It will be a trade off between arrival time which is planned as the preferred times by passengers and extra ground time.

Block time of any flight is the sum of time intervals of the flight such as taxi-out, take off clearing, cruising, descending, approaching, landing and taxi-in intervals. These time intervals are subject to the flight segment, aircraft type, direction of winds, aircraft take-off weight, etc. More time can be added to the block time as a buffer in case of disturbance is possible. The arrival time will be apparent in the timetable including the slack time.

Let us refer here to the extra ground time / block time added to the actual times as *slack time*. When the schedule plan has more slack time this will affect the utilization of the aircraft. Because aircraft will sit on ground more than needed in anticipation of disturbance occurrence.

Low utilization will lead to better punctuality levels in the sense that it will cater for the anticipated disturbance, but at the same time it will increase the operating cost. The extra operating cost represented by the cabin and cock-pit crews, extra wasted time, extra fuel and electrical power for engines, lights and air-conditioning system while in waiting.

As explained earlier, having high punctuality levels will keep or improve passenger revenues.

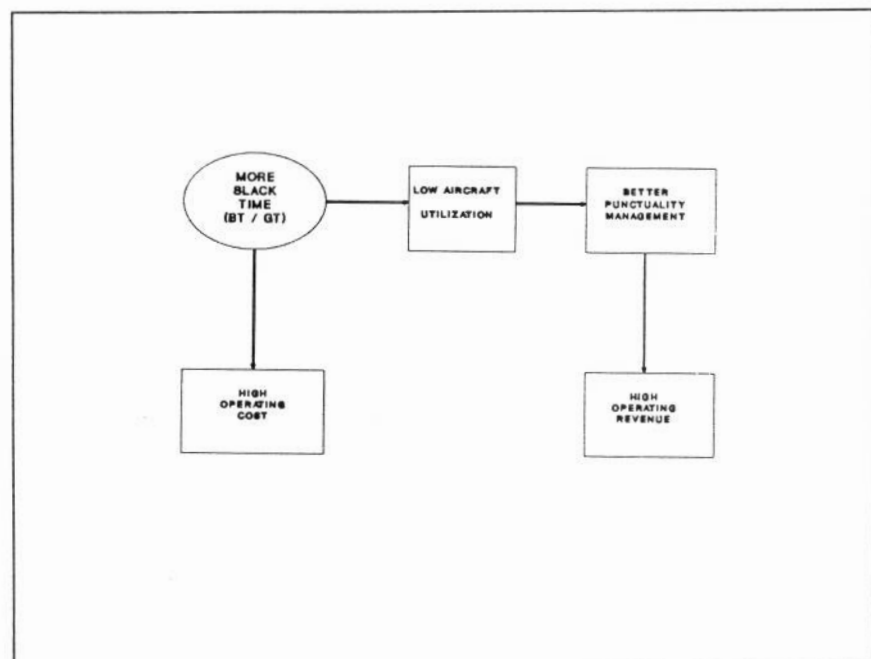


Figure 2-4 Schedule

Summary of Schedule Relationship:

Figure (2-4) illustrates that more slack times on ground and block times leads to less aircraft utilization. Low utilization leads to high punctuality levels in case of small disturbances but it also increases the operating cost. High punctuality performance affects the passenger revenues.

2.3.2 Output Variables:

Airline management is concerned with the economics of the schedule Operations. Normally *operating revenue and operating cost* are of major interest to airlines' top management.

a) **Operating Revenue:**

In most airlines passenger revenue is the major source of revenue. There are two ways of determining the operating revenue; by using the average ticket value (ATV) per passenger, or by using Yield Value Unit of revenue per seat per mile. These revenue units can be aggregated on a system or regional basis or more detailed by city pairs depending on the level of accuracy needed.

In the punctuality management system discussed here, operating revenue is determined by measuring the change in airline revenue in the case of occurrence of delays. *Revenue loss* is evaluated on the basis of passengers attitudes. This function is developed and discussed later in this thesis. Therefore, the higher the punctuality performance level the higher the revenue. And the lower the punctuality performance level the lower the revenue.

b) **Operating Cost:**

The operating cost is generally categorized as direct operating cost (DOC) and indirect operating cost (IOC) in terms of flying the aircraft. DOC cost elements differ from one airline to another. DOC elements and IOC elements are classified below based on International Civil Aviation Organization (ICAO) statistics and regulations. The following is the general cost distribution of the schedule airlines (DOGANIS (53)):

Direct Operating Cost (DOC):

Flight Operations	24.3%
Flight Crew Salaries/Expenses	4.3%
Fuel & Oil	15.8%
Airport & Enroute Fees	2.8%
Insurance & Aircraft Rental	1.5%
Maintenance & Overhaul	5.8%
Depreciation & Amortization	3.9

Total DOC **58.4%**

Indirect Operating Cost IOC:

Station and Ground	10.8%
Passenger Services	9.1%
Ticketing, Sales Promotion	15.5%
General & Administration	6.1%

Total IOC: **41.6%**

Total Operating Cost **100.0%**

The broad categorization of direct and indirect operating cost is useful when dealing with aircraft evaluation. To aid decision makers in their decision making the concept of "acceptability" of costs needs to be introduced. Airlines vary in the way they introduce the concept of acceptability into their costing procedures. The most usual way is by adopting the traditional accounting distinction fixed and variable costs. Airlines do this by taking those elements generally accepted as being direct operating costs and further subdividing them into "fixed" and "variable" costs (DOGANIS (53)).

Direct Operating Cost elements are structured on the fixed/variable cost basis:

Variable Cost

Fuel Cost
Variable Flight Crew Cost
Variable Cabin Crew Cost
Direct Engineering Cost
(Based on Cycles and
Block Hours)
Airport & enroute charges
Passenger Services (meals,
hotels)

Fixed Cost

Depreciation, Rental
Annual Flight Crew (Salary)
Annual Cabin Crew (Salary)
Engineering Overheads

Cost structure and cost allocation are complex processes and subject to discussion among internal divisions of the airline. As appears above the cost function is generally divided into variable cost and fixed cost. Variable cost involve elements which varies with the level of operations such as fuel and engineering cost. The flight crew cost has two elements one is fixed which is the fixed monthly salary and the other is variable cost which is the allowance based on the block hours. In the punctuality management system the change of cost is determined which occur due to the schedule disturbances. In other words, the output variable is the *extra operating cost* acquired to overcome a schedule disturbance. The details of evaluating the change in cost is discussed later.

c) **Punctuality Performance Level (PPL):**

Punctuality Performance level (PPL) is the third output variable that helps in monitoring the on time performance using different management decisions which are simulated on the system. The punctuality performance varies with different input variables values.

2.3.3 System Structure:

As discussed in the previous section aircraft, crews, reliability standards, slack times in schedule including ground time and block time and aircraft utilization are variables in the punctuality management system.

Figure (2-5) illustrates the punctuality management system structure. It shows the relationships between the systems input and output. The operating revenue loss, extra operating cost and punctuality performance level are output variables for this system. Slack times, schedule plan including aircraft plan and its utilization and airline resources such as manpower crews and reliability standards are the major input variables.

In the figure below a rectangular shape represents a system entity and a circular shape represents a model. Detail descriptions of the overall system are mentioned below and details of the models are illustrated at the next section.

Implementation of the schedule plan with slack times in flight block times and/or in aircraft ground times, using the system resources; aircraft, equipment and crews have some schedule disturbances. The disturbance model generates random delays based on a delay frequency distribution. These disturbances are in the form of aircraft delays. Operations and marketing try to eliminate such delays by taking different corrective actions as appropriate. These actions can be *diversion of other aircraft, substitution of different types of aircraft, employ more crews*, in case they are the reasons behind the delay. In spite of these corrective actions some flights will still have to be delayed. So *total delay time* becomes as a result of the recovery actions using airline resources including *spare aircraft* and slack time.

The delay time *influences passengers* future behaviour on selecting airlines. Naturally this impact varies according to the length of delay time and to the services presented to passengers while waiting. Again this impact differs from business travellers to vacationers. In any case this will affect the operating revenue due to *passengers trip loss which will lead to passenger revenue loss*. On the other hand *extra operating cost* is engaged due to these extra activities and facilities provided while recovery of flight delays.

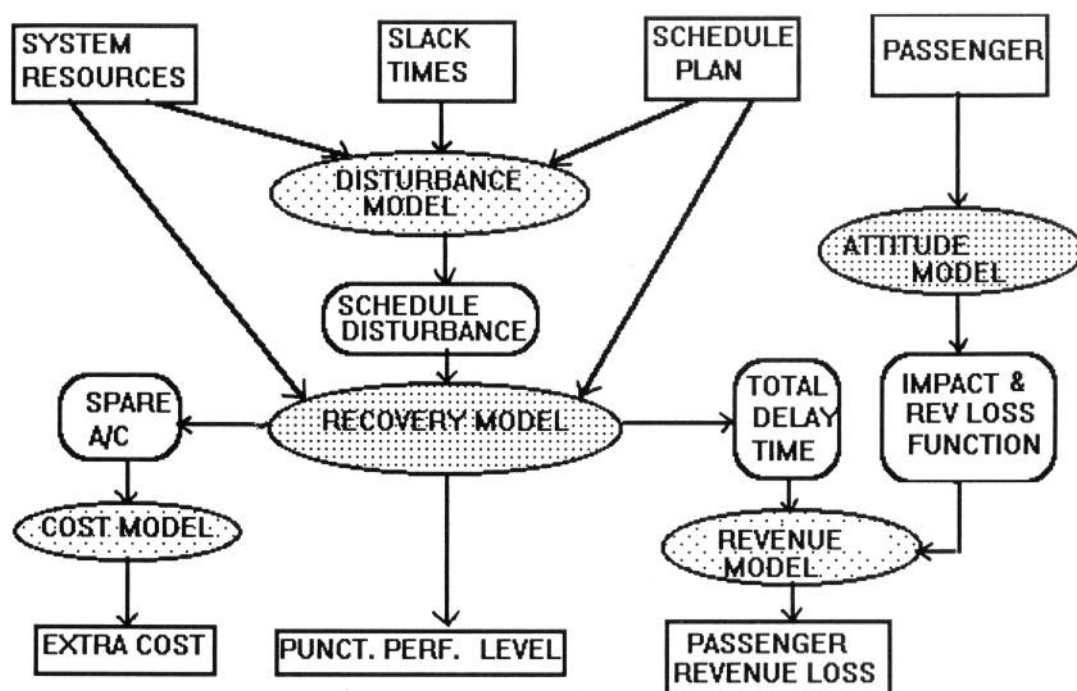
Operating Cost is the total operating cost of operating a schedule plan (DOC and IOC) plus the extra cost obtained from reducing the impact of disturbances to the schedule such as passenger services, accommodation, etc. Maintenance cost is considered as a fixed cost element in the cost elements breakdown mentioned earlier. The supporting argument that the maintenance cost is there and maintenance has to be there when needed. In case of a disturbance to a flight due to technical failure or defect and maintenance means are available then maintenance action shall be taken. Some of the equipment is a function of block hours flown, some are a function of time duration while some are a function of number of landings or departures.

The total operating cost is the sum of direct operating cost and indirect operating cost of running the schedule plan using the system resources available.

Revenue is the passenger revenue and the impact of the level of punctuality existing in the airline is measured in terms of revenue gain or loss. The impact can be positive where a generation of more demand and growth in passenger demand occurs, or can be negative where low punctuality impacts passenger behaviour in selecting the airline and consequently passenger loss.

When a schedule plan is initially disturbed because of equipment failure, a disturbance will occur in the form of a delay or cancelation. Then the airline resources ; available operational/spare aircraft, perform maintenance, change aircraft rotation plans are used. to avoid serious disturbances. As a result of such activities the flight will have one of the three situations; either no delay because recovery is performed while the aircraft is still on ground, or the flight is delayed for a period of time or lastly the flight is canceled in case of serious failure. In the scope of this research only the first two situations are considered. The total delay time is the factor which has an impact on passenger behaviour which consequently will influence operating revenue.

After explaining the punctuality management system structure, section 2.4 shows briefly a description of the basis and functions of the models involved.

Figure (2-5) Punctuality Management System Structure

2.4 MODELS:

There are five models in this system; disturbance model, recovery model passengers attitude model, revenue model and cost model,.

a) **Disturbance Model:**

Based on the schedule plan and system resources this model generates random *delays* according to delay rates existing in the system. Based on historical delay time distribution functions these delays assign a *delay time*. Delay rate (DR_{sys}) is defined as the number of delays expected for 100 departures on the entire schedule system.

Delay rate can be more specific if expressed for certain aircraft type (DR_{ac}) per 100 departures i.e. delay rate for B737 or A300. It can be expressed by month of delay (DR_{month}) such as delay rate for the month of June or August. For the purpose of demonstration this research consider delay rate by system (DR_{sys}).

The historical data is analyzed to develop the probability distribution function for delay times. These delay functions are used in schedule simulation model. On the aircraft cycle, a random number generator can be used to assign these delays to different segments in the cycle.

b) **Recovery Model:**

Schedule delays are inserted in the aircraft cycles. Using the airline resources and aircraft rotation plans with the inserted delays the recovery model will determine the propagated delays in the schedule which is not recoverable with the current conditions. This model is the most difficult model in Punctuality Management system. In practice, operational planners coordinate with marketing regarding diversion of another aircraft without affecting the departure of the flight which originally has been assigned to that aircraft. Other actions might be the diversion of spare aircraft in case of serious technical problems.

In this model the propagated delays are determined by simulation of the corrective actions taken by operations and marketing on the schedule which were subject to disturbances.

The input to the recovery model is the schedule disturbances given airline resources i.e. active and spare aircraft, schedule plans with different ground times, flights with delays and delay times. The recovery model is a schedule simulation model which demonstrates different management strategies on schedule development to determine the overall punctuality of the schedule plan. After *simulation of aircraft schedule plan* considering the model input and planners action, total delay time is determined. The output variable from this model is the total delay time and the punctuality management level. It also produced a measure of the required spare block hours made on the spare aircraft for different set of airline strategies including spare aircraft and slack time in ground time.

c) Passenger Attitude Model:

The purpose of this model is to determine the impact of delays (disturbances) on passengers and their attitudes towards the airline in future. An *impact function* is developed from the analysis of passengers interview surveys. For different passengers different impact function normally exist i.e. business and vacationers. The output from passenger attitude model are the impact function and the passenger loss function.

d) Revenue Model:

This model determines the change in revenue due to occurrence of schedule disturbances (delays). Revenue can simply be calculated on average ticket value basis (ATV), but the purpose here in punctuality management system is to demonstrate the effect of punctuality management strategies on airline revenue.

The input to the model is the total delay time occurring in the system after simulation and the *passenger revenue loss function* developed from the passenger attitude model. Then the output is the expected revenue loss expressed as a percentage revenue loss for a given delay time.

e) Cost Model:

This model determines the change in total operating cost due to the occurrence of schedule disturbances. Normally airlines have extra operating cost committed when delays or cancellation occurs. The extra operating cost is due to additional operating block hours emerged either from deviation of an active aircraft or from allocation of a spare aircraft.

Of course many areas lead to extra cost i.e facilities provided to passengers to ease delays impact, food and beverages offered to passengers, non/less utilization of aircraft and crews, abnormal maintenance cost, etc. In this punctuality management system cost model consider the extra cost resulting from additional block hours required as a spare block hours from spare aircraft.

The input to the cost model is the total block hours used by spare aircraft which is the output of the recovery model. The output of the model is the *expected extra cost percentage* due to operating these spare aircraft.

2.5 MANAGEMENT DECISIONS SUPPORT:

In the previous mentioned management responses and strategies to the airline punctuality management, the complexity of these decisions and the importance of changing strategy or adopting a new one in the overall airline economics was demonstrated.

For example if slack times are introduced to the schedule either in flight block time and/or in aircraft ground/turn-around times, then a chance of better disturbance recovery exists therefore the disturbance is reduced and consequently operating revenue and operating cost is influenced.

Similarly, other management strategies are interrelated and improve punctuality performance but also affect airline resources and airline economics. Airlines are using different sources of information to manage punctuality. Some of these resources are computer reports, reliability and quality assurance reports and some are verbal notices.

There are other internal variables which influence the punctuality system. Effective management of these parameters is difficult including monitoring and controlling of the variables performances.

Therefore due to the involvement of many variables in this decision process and if a systematic punctuality management system is to be structured then a computerized based information system will also help the decision makers and can be considered as type of decision support system (DSS). The major layout of this decision support system and the practical implementation are introduced and organized in chapter 10.

Chapter 3

DELAYS ANALYSIS

This chapter discusses airline schedule punctuality disturbances and analysis including development of the delay distribution functions. An overview of the definitions of the major sources of schedule disturbances and background of the used sample data in the statistical analysis are introduced in section 3.1. Section 3.2 explains the overall analysis of schedule punctuality disturbances including flight delays and cancellations. Section 3.3 focuses on delays as the major source of disturbances. It analyzes the general delays including delay definition, formulation of delay frequency distribution function and delay time distribution function for the used sample data. Then section 3.4 goes one step deeper to show the categorical delay analysis of the general delay including classification of marketing, technical or operational delay categories. Section 3.5 shows in depth analysis of the general delays in which the general delays are classified into four types of delays; original delays, reactionary delays which occur as a result of original delays (the arrival delays). The third type is connection delays and fourth is other type of delays which are not included in any of the above mentioned delay types. Then it is followed in section 3.6 by analysis of variance for all delay types. The basic relationship between the original delays and reactionary delays is discussed in section 3.7.

3.1 INTRODUCTION

Schedule punctuality is disturbed by flight delays and/or flight cancellations. Delays can occur for different reasons either due to internal or external deficiency. Cancellations of scheduled flights occur often due to serious technical or non technical problem at which recovery time is long or unavailability of equipment exists. These are the two forms of schedule punctuality disruptions.

Delays are defined in theory as follows, "The delay for a given movement can be defined as the time difference for that movement with or without interference from other movements". Thus, in the case of airport, an aircraft does not experience delay if its desired movement can be performed without having to wait for completion of another aircraft movement. In this analysis, delays are generally defined as the difference between actual departure/arrival time minus scheduled departure/arrival time.

For purpose of delay analysis, a *delay sample data* is analyzed and it involves all flights with a delay time more than 5 minutes. Data includes flight number, flight segment, schedule aircraft code, actual aircraft code, and *three intervals of delay code number and delay time* in minutes. The sample size of delay/cancellation data is composed of 85045 flights for all Saudia domestic and international schedule during a year. For the same period *flight departures* statistics are examined. Based on delay classifications and coding illustrated in Appendix (A) delay code numbers are given. An example of the data analyzed is shown in the **figure 3-1** for illustration purposes. For example, flight # 047 from Jeddah to London scheduled with Boeing 747 is actually flown with the same aircraft half an hour later. The delay code is 03. Flight # 353 has two delays; first delay for 17 minutes because of passengers held with immigration and the second delay for 25 minutes because of security check.

FLT	ORG	DST	SKD A/C	ACT A/C	1ST DELAY CODE/TIME	2ND DELAY CODE/TIME	3RD DEL CODE TIME
047	JED	LHR	747	747	03	0.50	
353	RUH	JED	747	747	83	0.17	82 0.25
041	RUH	TUU	L10	L10	32	0.17	22 0.25 84 0.12
293	JED	DAM	A30	A30	41	4.45	
192	SAH	RUH	A30	A30	40	0.38	03 0.92
388	RUH	MNL	747	747	31	0.37	

Figure 3-1

3.2 PUNCTUALITY DISTURBANCES:

The disturbances to the airline schedule are due to two different instances either delays or cancellation. If the flight is anticipated to be delayed more than 10 hours, the flight is cancelled. This limit is an airline internal decision it can be different in other airlines.

The analysis of flight by flight data shows that out of 85,045 total departure flights, 72233 flights were on time (85%) and 12,812 flights were disturbed (15%). 9% of total departure flights were delayed more than 5 minutes and 6% were cancellations. 8.5% of total departures flights were delayed more than 15 minutes. **Figure 3-2** illustrates the overall analysis of schedule operational performance.

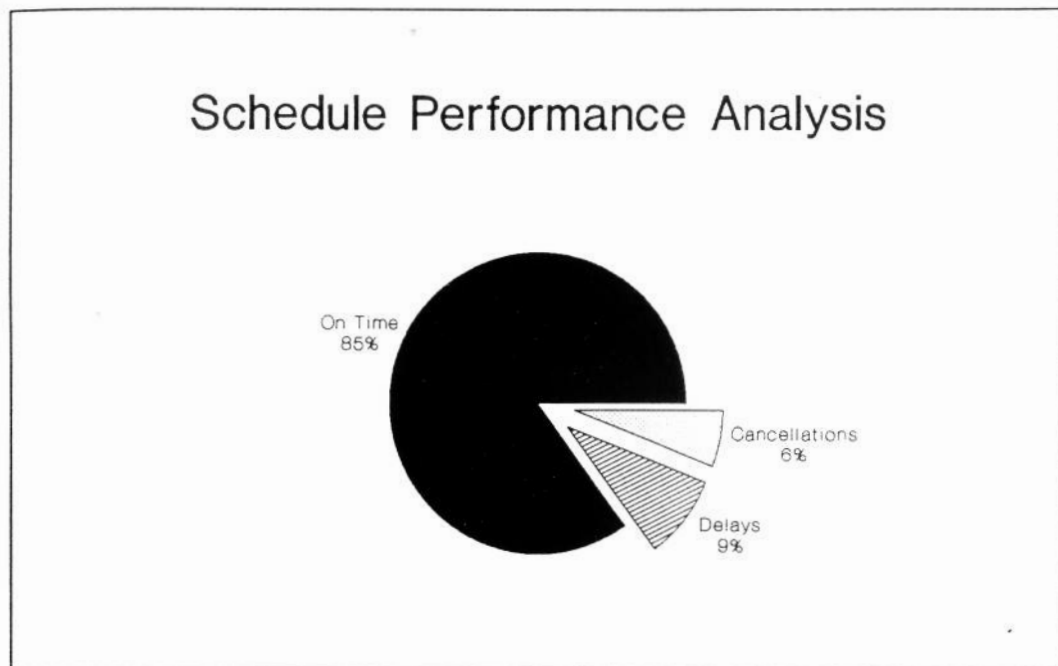


Figure 3-2

The major finding from this section is that schedule disturbance affects 15% of total schedule departures. This includes cancellations which are represented as a long delay in the simulation model (chapter 6). The analysis of delay disturbances are discussed in detail later in this chapter.

3.3 ANALYSIS OF GENERAL DELAY:

The general delay function is defined as all delays incurred in the system which is more than five minutes difference between Actual Time of Departure (ATD) and Schedule Time of Departure (STD).

The general delay analysis is approached by defining two distribution functions. The first is *General Delay Frequency Distribution* and the second is *General Delay Time Distribution*. The delay frequency distribution function shows the frequency of flight delays at an interval of time while delay time explains the total delay time occurred from delays at an interval of time.

3.3.1 General Delay Frequency Distribution:

A delay frequency histogram shown in **figure 3-3** illustrates the delays for an interval of 0.10 of an hour (six minutes). This interval is selected intentionally because it would be appropriate to use the histogram data for frequency distribution function later.

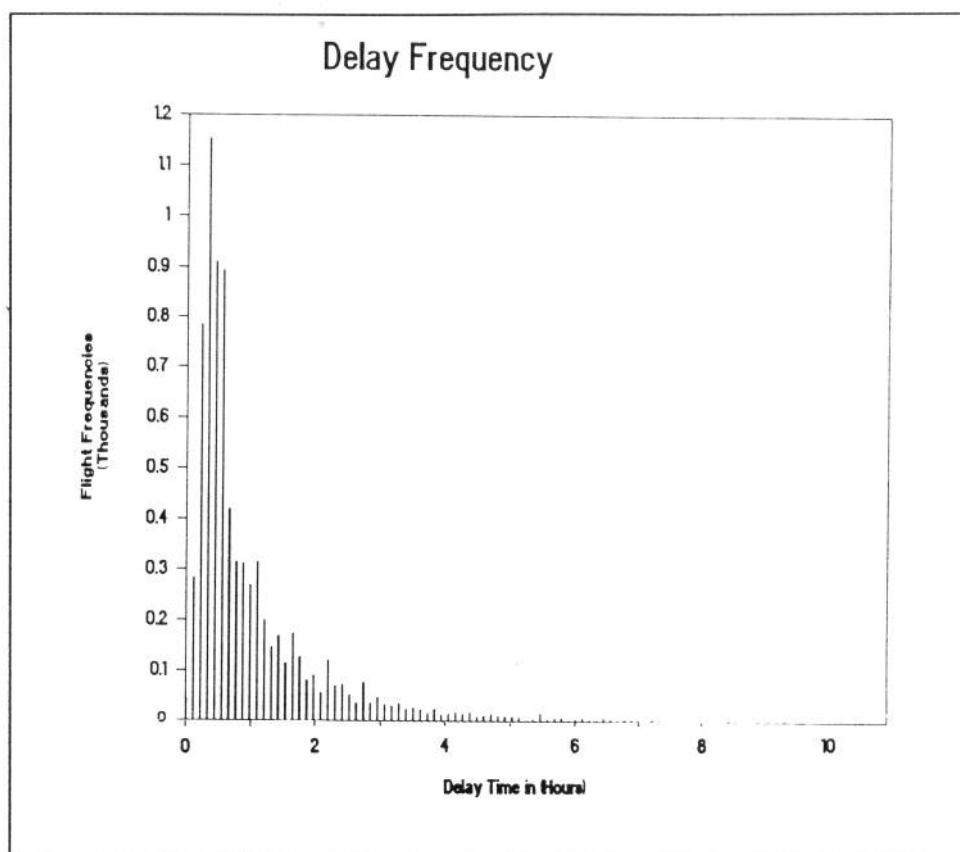


Figure 3-3

Figure 3-4 shows the *general delay frequency* distribution function. For delay time duration within 24 minutes the frequencies increase very radically to the top about 1,150 delays, for the delay time between 25-45 minutes, the function starts decreasing steeply. Actually four data points were almost representing one group of data which have 300 delays for a delay duration between 42-66 minutes. For delay time more than 66 minutes, the frequency function is decreasing and approaching zero delay value for 10 hours delay time.

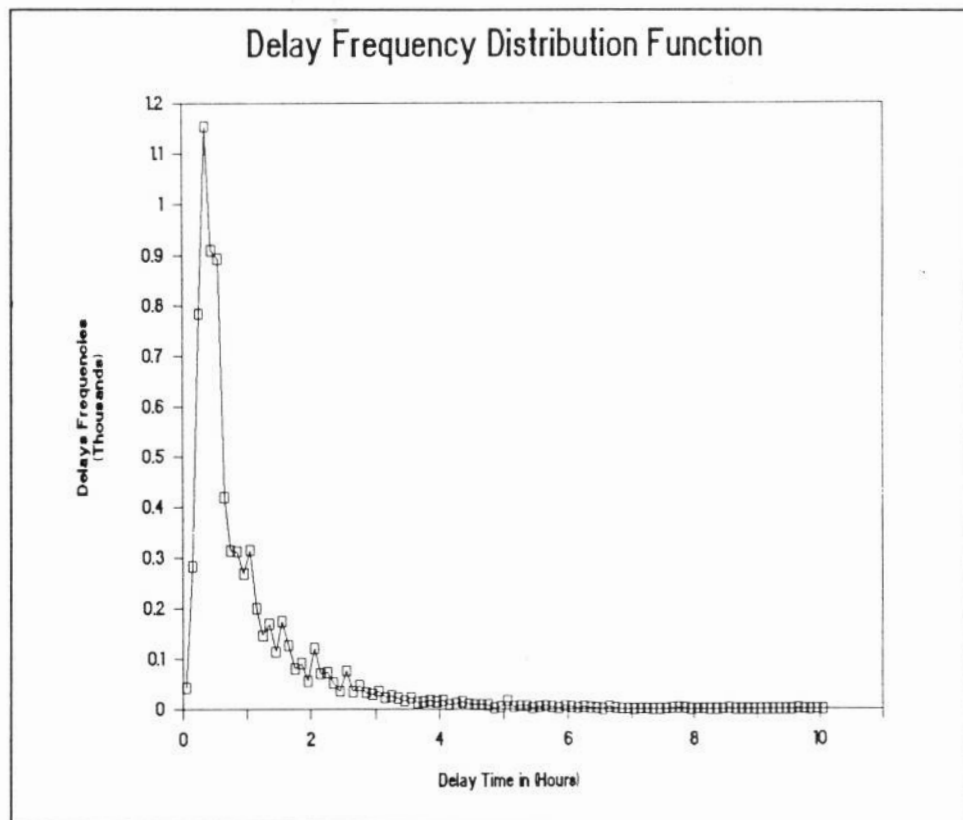


Figure 3-4

3.3.2 General Delay Time Distribution:

Delay time is defined as the duration of the delay in hours incurred from the frequency distribution function. There are two ways to develop the delay time distributions either by adding up all delay durations in each interval in the general frequency distribution or by multiplying the mid point of the interval value of the delay time times the number of total delay frequencies incurred in that interval.

The second approach is adopted in this research because the selected interval size of the histogram is small enough to represent the actual behavior of the function.

Figure 3-5 shows the *General delay time* distribution. The delay time increased to the top (about 480 hours of delay) for the delay durations within 36 minutes, then the function starts decreasing rapidly to 260 hours at one hour delay durations. For more than one hour delay durations the delay time decreases but not smoothly.

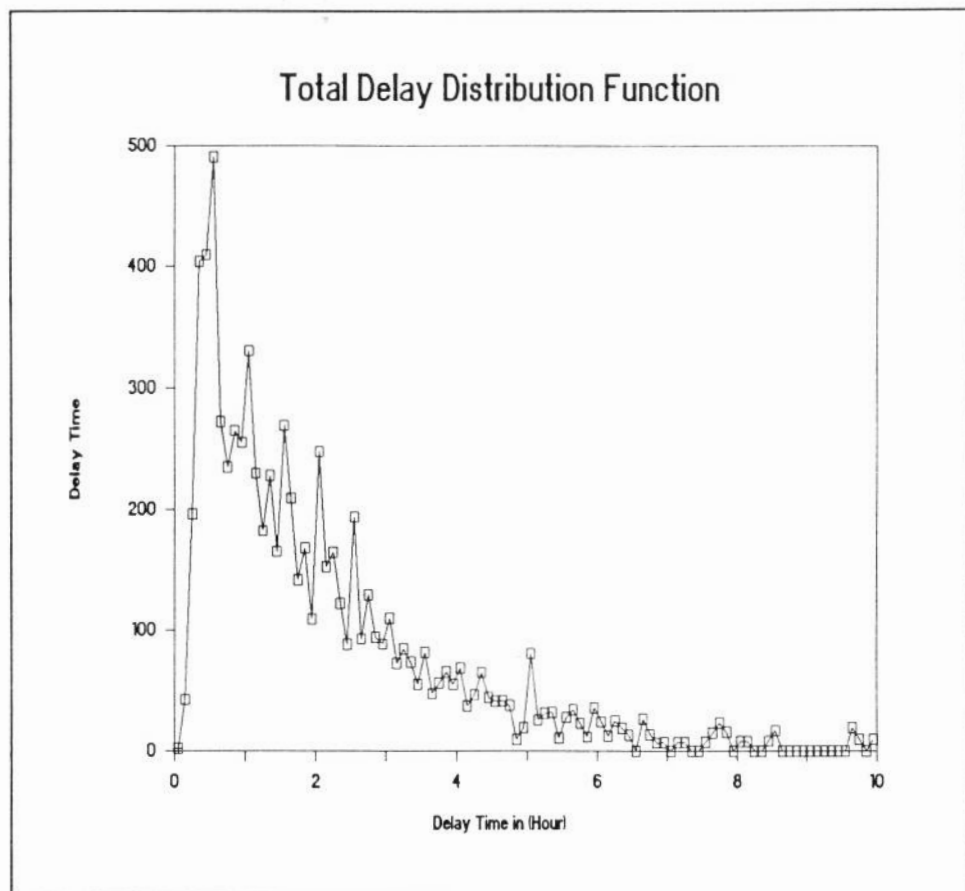


Figure 3-5

A comparison of both general delay frequency and delay time distribution functions is illustrated in **Figure 3-6** in which the delay time is much less than delay frequencies for delay duration for the first 36 minutes. In general delay time is less than delay frequencies for less than one delay time. Delay frequencies are similar to delay time around one hour duration. After one hour delay duration the delay time function is always higher than the delay frequencies.

3.3.3 General Delay Statistics:

Mean time of delay	0.9892
Standard Deviation:	1.0726
Variance:	1.1504

All the above descriptive statistics are in hours.

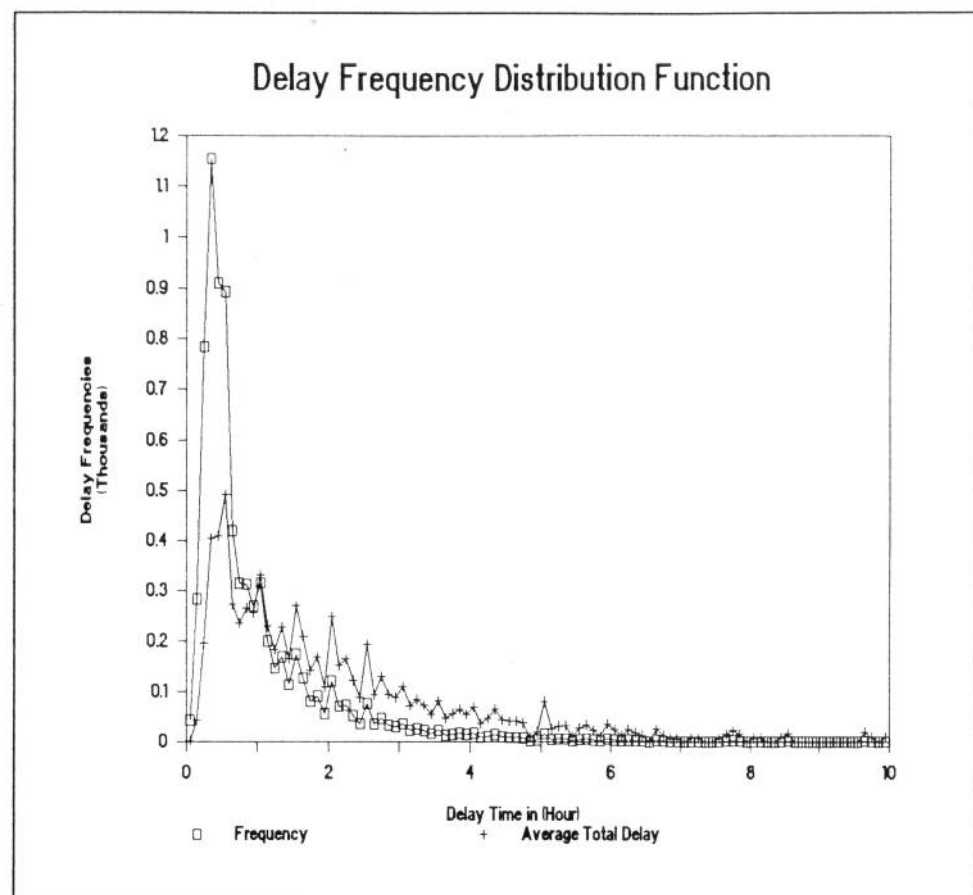


Figure 3-6

3.4 Delay Categories of General Delay Function:

As mentioned earlier each flight delay is classified and assigned a delay code. Delay classification is normally given by task force which represents different operation areas in the airline using pre developed delay codes within the airline. These delay codes are updated every year after discussing it with the concerned areas in the airline trying to cover all delay codes might exist in the airline operations and taking in consideration their previous year experiences. Then these delay codes will be considered as corporate reference and the airline will issue a written procedure for handling delays and code assignment. Delay codes are discussed in details in Appendix (A) including Delay categories and types of delays under each category.

Delays are classified under nine different delay categories. The delay category involves a group of delays that have similarity in terms of the division of responsibilities. This classification is very useful for understanding the delays causes and also for accountability purposes. The delay codes are nine categories; Airline Internal Use (AIU), Marketing (MKT), Technical (TECH), Material Management (MAT), System Delay (SYS), Flight

Operations (FOPS), Weather (WXR), Airport & Government (GOV) and Miscellaneous (MISC). Details of delays involved in each delay category is explained later in the following sub sections.

Figure 3-7 illustrates the percentage of the general delay categories for both delay frequency and delay time distribution functions. It is clear that the major delay category are technical (TECH) and marketing (MKT) which in turn generate a major arrival delay which is called here as airline internal use (AIU). Marketing delays occur more frequently but with little delay time as observed from the chart differently from technical delays.

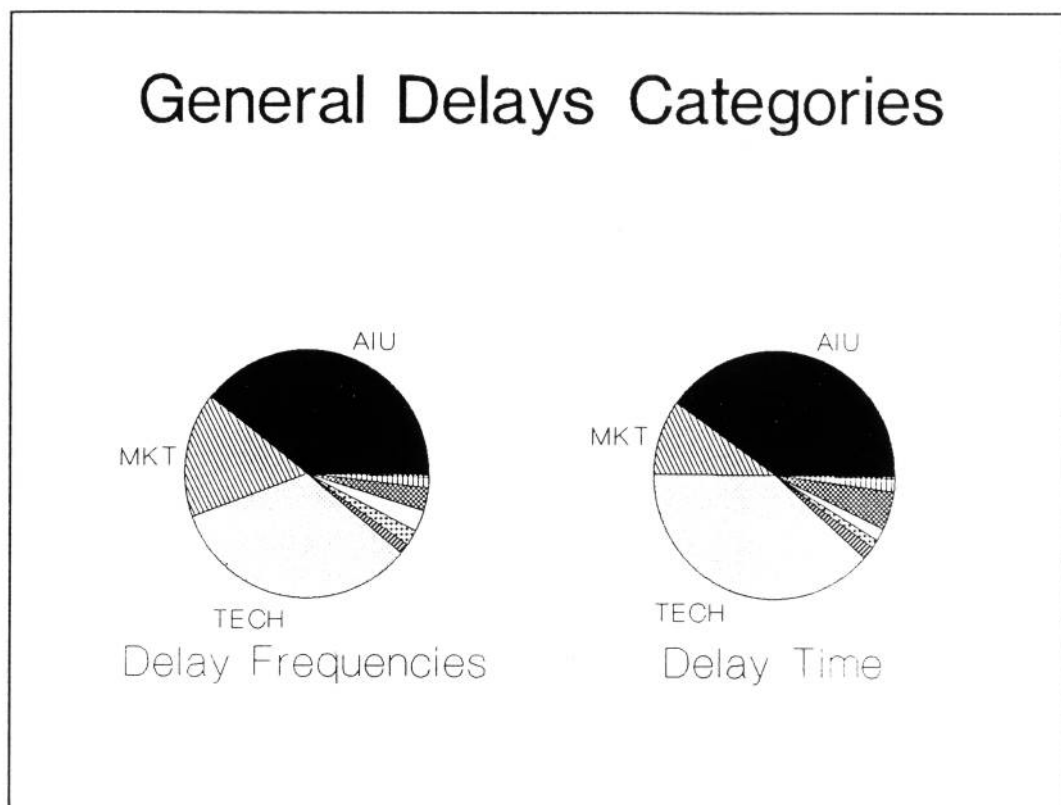


Figure 3-7

Table 3-1 contains delay statistics for each delay category of the general delays. Statistical Package for Social Sciences (SPSS PC+) is used to analyze the down loaded delay data and obtain similar statistics on data breakdown (60). SPSS PC+ like other statistical package requires definition of the structure of the data file. Many SPSS PC+ programs are written to do the statistical analysis for different delay categorical analysis. Appendix (B) shows some of those programs used in the analysis.

Table (3-1)

<u>Delay Category</u>	<u>Mean (Hour)</u>	<u>Std Dev</u>	<u>Var</u>
1.0 Airline Internal Use	1.01	1.13	1.27
2.0 Marketing	0.59	0.69	0.48
3.0 Technical & Aircraft	1.14	1.05	1.10
4.0 Material Management	1.21	1.63	2.67
5.0 System Delay	0.54	0.34	0.12
6.0 Flight Operations	0.59	0.69	0.47
7.0 Weather	1.65	1.52	2.32
8.0 Airport & Govt.	1.21	1.32	1.74
9.0 Miscellaneous	0.99	0.97	0.94
Total Population	0.99	1.07	1.15

a) **AIRLINE INTERNAL USE (AIU):**

Delay codes included in this category are equipment shortage and *reactionary delays*. Equipment shortage is resulting from unscheduled aircraft movements to serve flights for transporting teachers from/to different countries within the Middle East during school start/break periods, transport pilgrims from all over the Muslim world during Haj period, transport passengers on heavy periods as an extra flights, etc. This shows the different peak seasons that might happen to Saudia. The reactionary delays can be defined in more details as the propagated delay from previous delays caused by marketing, materials management, maintenance, automation system, flight operations, weather, airport authority and airport closure.

Airline internal use has the maximum share of delay time and delay frequency from the general delay (40.25% and 39.52% respectively), but a **high percentage of airline internal use category is the reactionary delays** (arrival delays) which represents the propagation delay caused by *late arrival or turnaround* of equipment in the previous sectors. Actually the reactionary delays are the factor behind increasing the airline lateral use (AIU) category. Almost 75% of AIU delay times and 65% of AIU delay frequencies are reactionary delays.

Delay Frequency Distribution:

The delay frequency distribution for Airline Internal Use is similar to the general frequency distribution. As it appears in **figure 3-8** the AIU delay frequencies increases to the peak value for about half an hour delay time then declines sharply for the second half of the hour. AIU has the

highest peak of the function around 420 delay frequencies at 24 minutes delay time. This means that most of the reactionary delays occurred under one hour delay time approximately.

Delay Time Distribution:

Figure 3-9 is the AIU delay time distribution function. Peak point is 185 delay hours at 36 minutes delay time duration.

b) MARKETING (MKT):

Marketing is the third top category in general delay. Almost 16% of general delay frequencies and 10% of general delay time is categorized as Marketing. Average of delay time is small compared to the rest of the categories. Mean value is 0.59 hour with 0.48 hour variance.

Delay frequencies due to *immigration and customs* is 25% of Marketing delay frequencies and 20% is due to *security*. 16.5% of marketing delay frequencies is caused by *connections*. Other smaller percentages for late check-in after closing counters and for loading or unloading passengers (6% and 6.2% respectively). Other delay codes included under *Marketing Delay* in areas of passenger & baggage, cargo and ramp handling.

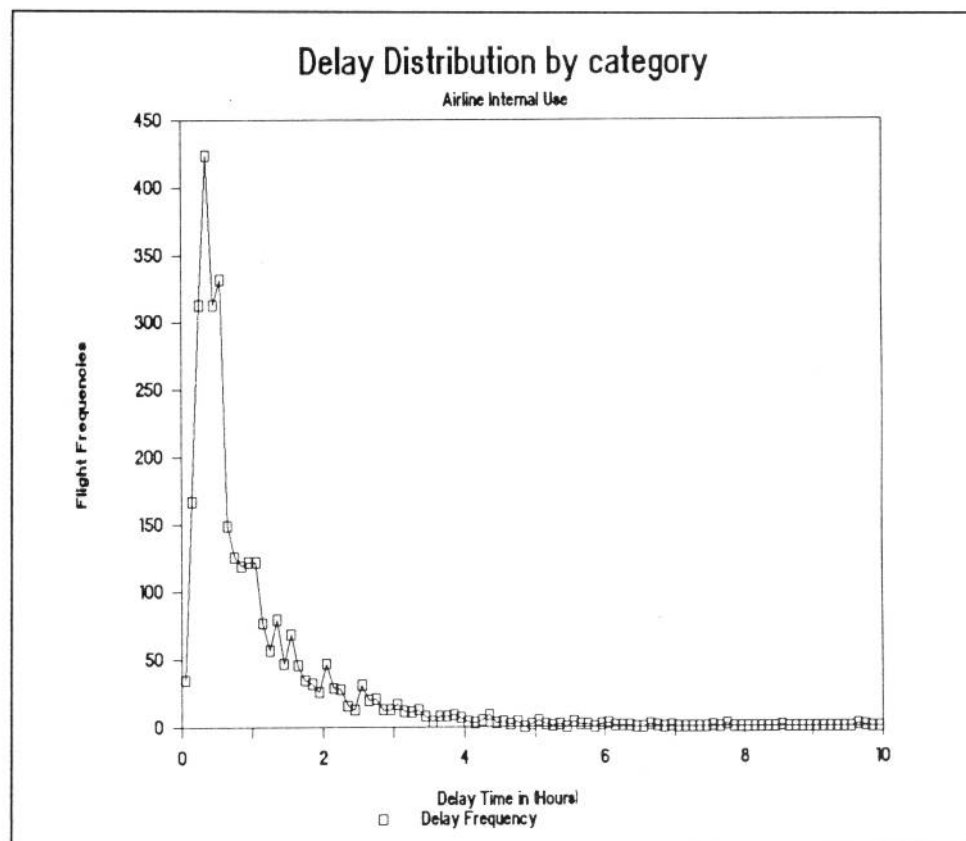


Figure 3-8

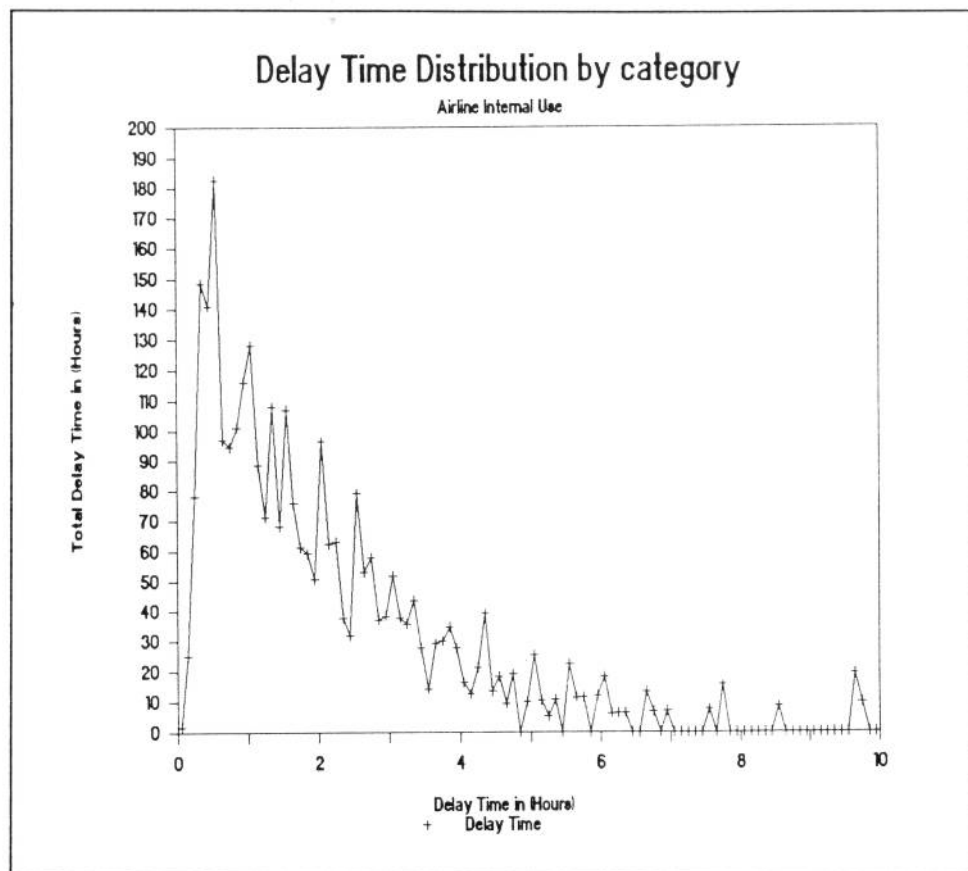


Figure 3-9

In *Passenger & Baggage*, delay codes can be late check-in - acceptance after deadline, late check-in - congestion at check-in area, check-in error- passenger and baggage, over sales booking errors, boarding - discrepancies and paging, commercial publicity / passenger convenience, illness/death - connections, catering order - late or incorrect order given to suppliers and baggage handling.

In *Cargo*, delay codes can be documentation errors, late positioning of cargo, sales decision - discretionary for late acceptance of cargo/mail, inadequate packing, over sales booking errors and incorrect build-up of ULD.

In *Aircraft & Ramp Handling* delay codes can be Aircraft documentation in weight and balance, general declaration, passenger manifest, payload and fuel release. Loading/unloading ULD i.e. bulky special load, cabin load, lack of loading staff. Loading equipment i.e lack of hiloader, steps, conveyor belts, tractors. Servicing equipment i.e lack of or breakdown, lack of staff to operate. Aircraft cleaning, catering i.e late delivery to loading, late cabin crew boarding - on departure procedures, cabin crew shortage - sickness, awaiting standby, flight time limitations, crew meals, valid visa, health documents. Security - involving pax/cargo, immigration, customs and health.

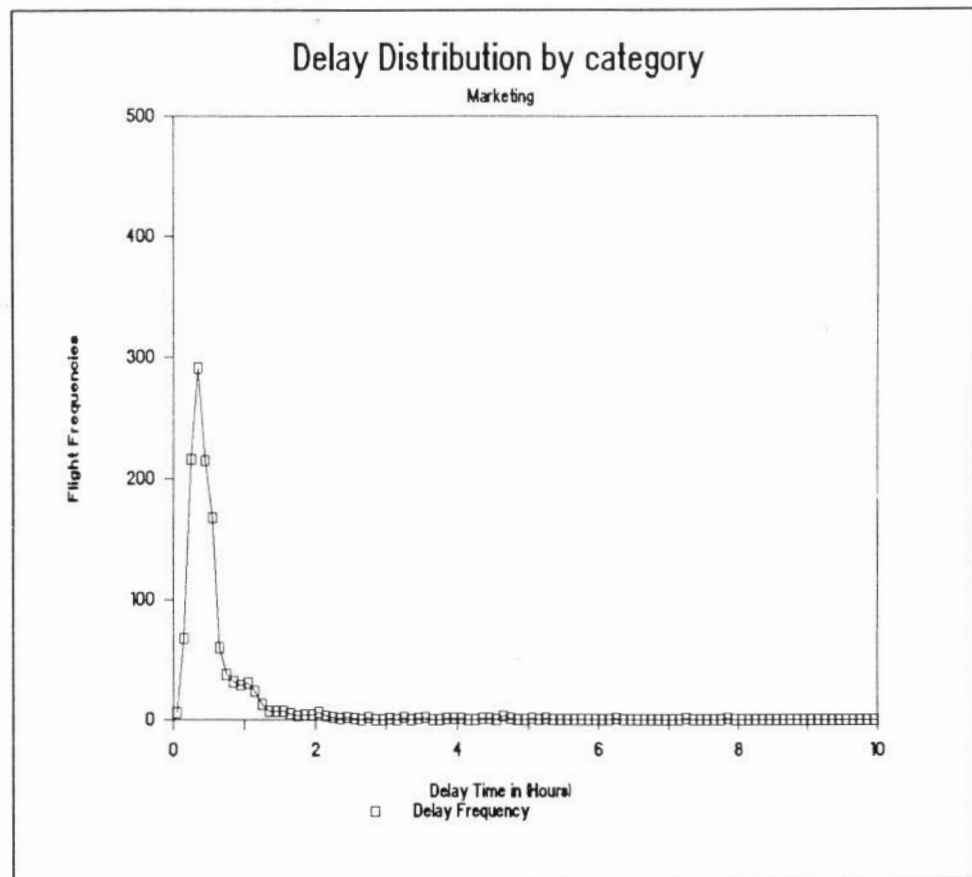


Figure 3-10

Delay Frequency Distribution:

Marketing delay frequency distribution function appears in **figure 3-10**. Almost 280 delay frequencies are on the peak at a mode of 20 minutes of delay time duration. For more than 25 minutes delay duration the delay frequency function decreases smoothly and after one hour approaches zero quickly.

Delay Time Distribution:

Figure 3-11 illustrates the delay time distribution function for Marketing category. Mean of delay time is 0.59 of hour with variance of 0.48 hour. Peak total delay time is about 100 hours at 20 minutes delay time duration.

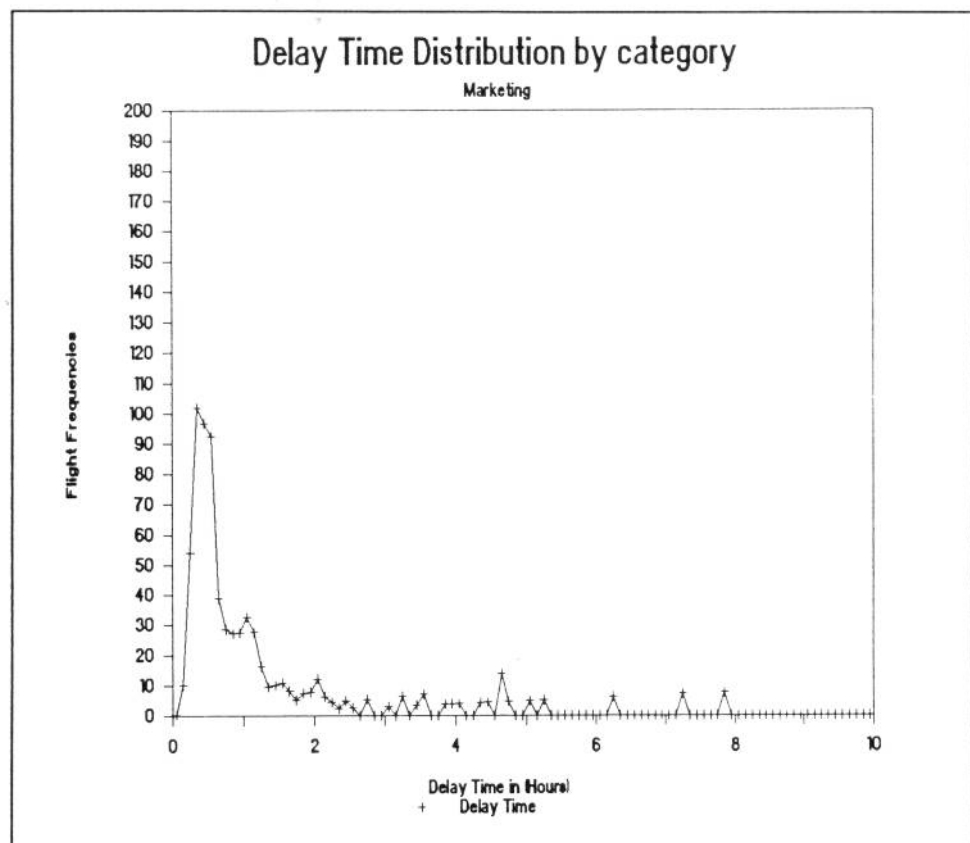


Figure 3-11

c) **TECHNICAL AND AIRCRAFT MOVEMENT (TECH):**

Technical and Aircraft Movement is the second top category for the general delay. 38.54% of general delay time and 33.34% of general delay frequency is due to technical and aircraft movement problems. Mean value of delay time is 1.14 hours with 1.1 variance.

Aircraft defects are the biggest reasons for delays where 67% of technical delay frequencies and 72% of technical delay times occurred because of *aircraft defects*. The second highest is *aircraft change* at which 15% of delay frequencies and 20% of delay times occurred due to aircraft changes for technical reasons.

Other delay codes can be due to lack of Maintenance Equipment / Servicing Equipment or breakdown, lack of staff to operate them, Aircraft Defects Due to Technical Problem i.e Malfunction of aircraft, engines or component parts thereof, Scheduled Maintenance, Non-Scheduled Maintenance, Aircraft Change for technical reasons, Lack of standby aircraft for technical reasons, error or negligence by Technical Personnel, Routing of aircraft for maintenance considerations or transporting of Technical personnel and/or tooling and equipment for AOG Aircraft at another station and Airport Facilities i.e parking stands, ramp congestion, lighting, buildings, gate limitations, mobile lounge.

Delay Frequency Distribution:

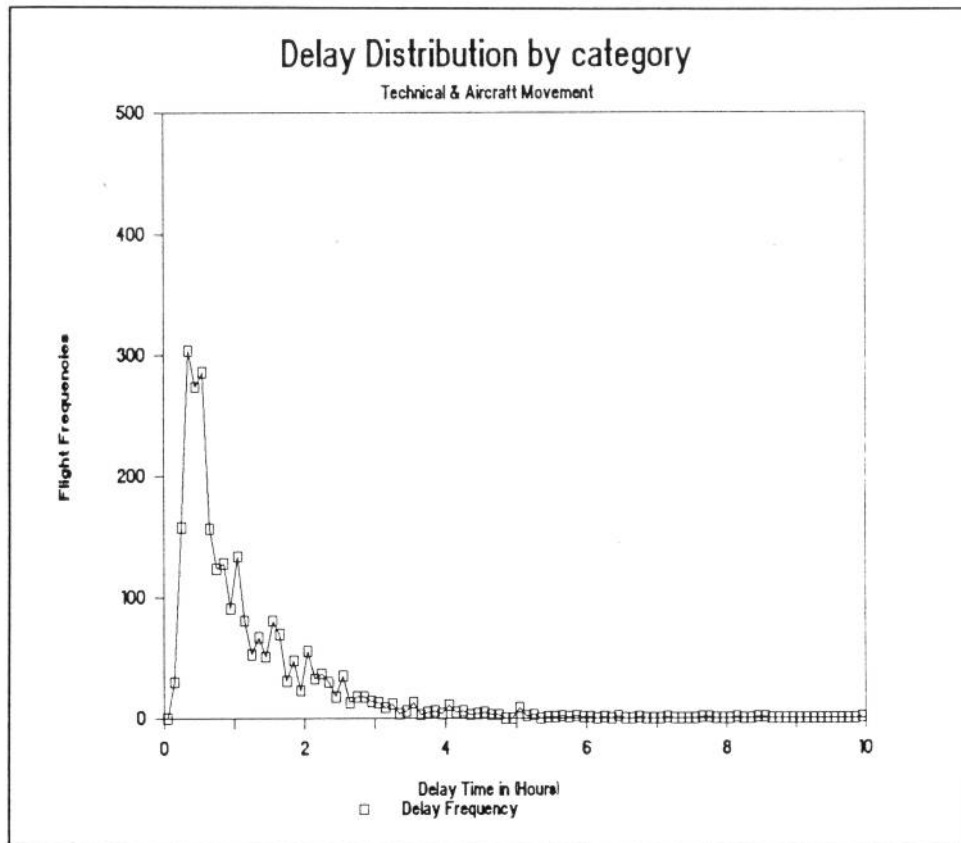


Figure 3-12

Figure 3.12 has the Technical delay frequency distribution function. Peak point of the distribution is 300 delay frequencies at mode of 20 minutes delay time duration. About 260 technical delay frequencies between 30-36 minutes. For more than 36 minutes delay time duration the delay frequencies start decreasing exponentially until it approaches zero.

Delay Time Distribution:

Figure 3.13 represents the technical delay time distribution function. Peak point is 160 delay hours at 36 minutes delay time duration then the function starts declining.

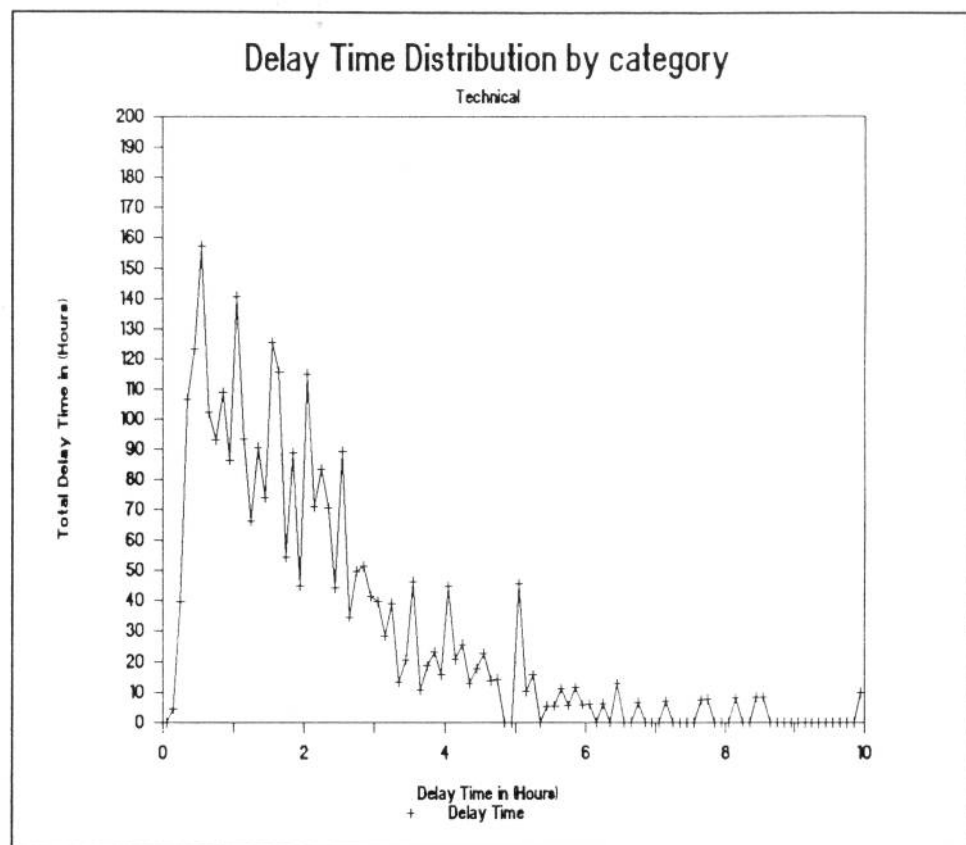


Figure 3-13

d) **MATERIAL MANAGEMENT:**

Delay codes included in this category are delays due to fueling/defueling, lack of spare parts, AOG spares (Aircraft On Ground) which requires normally to transport spare parts from different station or main base or sometimes from abroad.

The material management category has a small percentage of the general delay functions but variances are higher as compared with other categories variances. The mean of material delay time is 1.21 hour with variance of 2.67. The variance is double the mean time.

The delay frequency distribution is smaller than other delay categories. It approaches zero quickly after one hour delay time duration.

The delay time distribution shows higher total delay time for a specific delay time greater than one hour delay time duration. Such delay codes as AOG (Aircraft on Ground) which has a mean value delay time of 1.87 hour and variance of 11.5 hours.

e) **WEATHER CONDITIONS:**

Weather delay category includes delays result from weather conditions in departures station, destination station, enroute or alternate, deicing, de-snow, removal of snow and ground handling.

Weather category seems to be the only category where the percentage of delay time is significantly higher than the percentage delay frequency. 2.95% of general delay frequency and 4.93% of general delay time. Mean of weather delays is 1.65 hours with 2.32 hours variance.

f) **SYSTEM DELAYS (SYS):**

2% of general delays are due to systems such as automated equipment. Major system delays are delays due to *automated equipment for departure control* which represent 96% of system delay frequencies. Mean of system delay time is 0.54 hour with 0.12 hour variance.

g) **FLIGHT OPERATIONS (FOPS):**

The major factor for delays in Flight Operations category is **Air Traffic Services Control (ATC)** which represents 41% of Flight Operations delays. Average delay time of flight operations category is 0.59 hour with variance equal to 0.47 hour.

Other delay codes in this category are non completion or change of flight documentation / plan / general declaration, operational requirement, late flight deck crew boarding or departure procedures i.e. flight deck crew shortage, sickness awaiting standby. Flight time limitations crew meals, valid visa, health documents, late arrival of flight deck crew, etc. Late flight deck crew boarding or departure procedures, error or negligence by operations personnel, air traffic services clearance, including ATC and movement control includes re-routing, diversion, consolidation, cancellation of flights for reason other than technical/operational decision.

i) **AIRPORT AND GOVERNMENT (GOV):**

Delays includes all delays happened due to airport restrictions, airport closure, limited number of gates/stands and other operational constraints.

Less than 2% of general delays and delay times are due to airports or government authorities such as airport closures or ATC of runways, etc. Mean of delay time is 1.21 hours and variance is 1.74 hours.

Delay frequency distribution function and delay time distribution function graphs are enclosed in Appendix (B).

3.5 TYPES OF DELAYS:

In this research, all system delay codes are classified into four delay types according to similarity of causes and effects. These type are original delays, reactionary delays, connection delays and others. In this section an overview of these delay types will be given and basic statistical analysis is presented.

Figure 3-14 shows the percentage of delay frequency and delay time by type of delay. Original delay is the largest percentage of the general delays (61%) while about one third of the general delays are propagated in the schedule due to the original delays (30%).

Table 3-2 shows the statistics of the all delay types. Original delays behave in a similar way to the general delays because most of the general delays are original as discussed earlier. Reactionary delays have a different behavior from the general delay, average of delay is 1.16 hours with 1.40 hours variance.

Table 3-2			
<u>Delay Type</u>	<u>Mean</u>	<u>Std Dev</u>	<u>Var</u>
	<u>(Hour)</u>		
Original	0.99	1.03	1.07
Reactionary	1.16	1.18	1.40
Connecting Flts.	0.69	0.92	0.84
Misc. / Others	0.63	0.93	0.86
Total	0.99	1.07	1.15

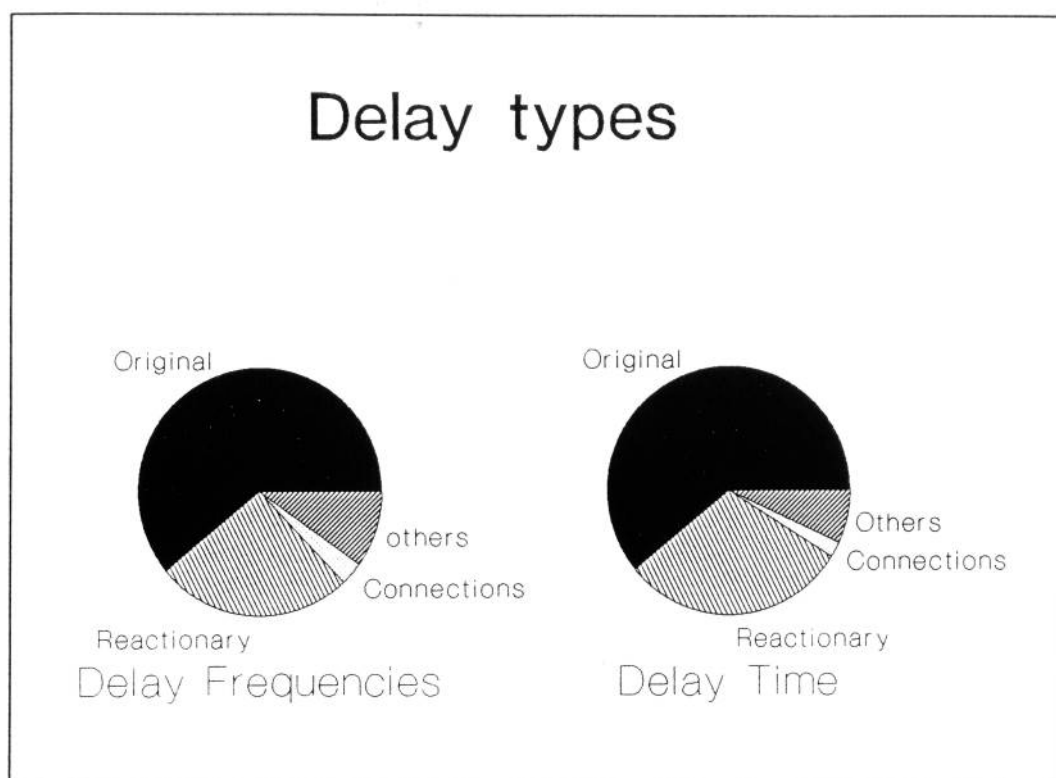


Figure 3-14

a) **Original Delays:**

This type of delay contains all delay codes which cause schedule disturbances except for airline internal use (AIU) delays. This type of delay considers the delays which occur at the departure of the flight (departure delays) without considering the delays exist at the arrival of the aircraft (arrival delay).

As appears in figure 3-14 that 61% of all general delays are original delays which cause 61% of total delay time. The mean of original delays is 0.99 hours with 1.07 hours variance. Aircraft defects delay were the highest delay code representing 36% of the original delay type while total delay time of aircraft defects represents 28% of original delay time.

Figure 3-15 illustrates the original delay frequency distribution. Peak of delays is 700 delays at 21 minutes of delay time duration. **Figure 3-16** shows the delay time distribution for original delay type. Original delay frequency and delay time distributions are similar, in the shape, to the general delay frequency and general delay time distribution functions.

b) **Reactionary Delays (Arrivals):**

This delay type contains all delays which are propagated in the schedule due to prior original delays which will cause late arrivals. The reactionary delays are represented by airline internal use (AIU) delay codes only which is explained in appendix (A). In other words, each aircraft has a rotation plan which illustrates its scheduled operation for that day/week.

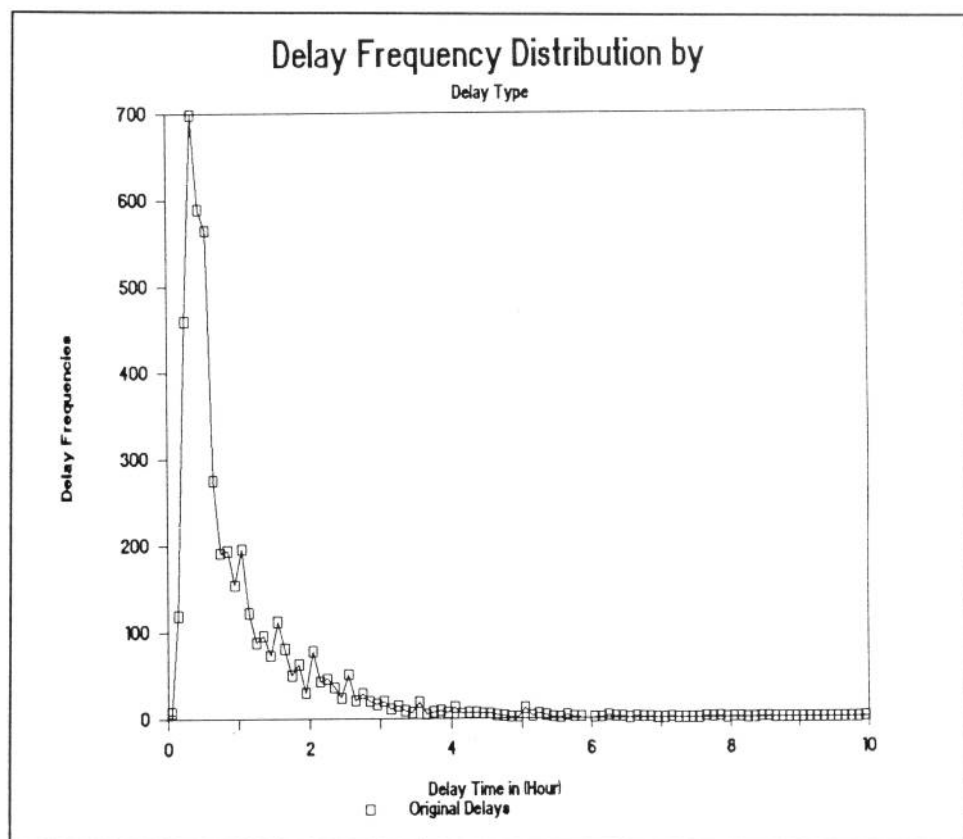


Figure 3-15

Aircraft have to fly each flight in that plan as scheduled unless there is a delay. If a flight had an original delay from any delay category then this delay time will register as an original delay in the first flight of that plan, then the same delay will be propagated to the next flight which is considered in the second flight as an arrival delay. A flight might have an arrival delay due to previous delays and/or original delay occurs at the departure station. Arrival delay is called here as reactionary delays. Eight reactionary delays exist which represent a late arrival delay due to marketing, technical, flight operations, etc delays.

26% of the general delay frequencies are reactionary delays and 30% of the total delay times caused by reactionary delays. Mean of delay time is 1.16 hours (higher than the original delays) with 1.40 hours variance.

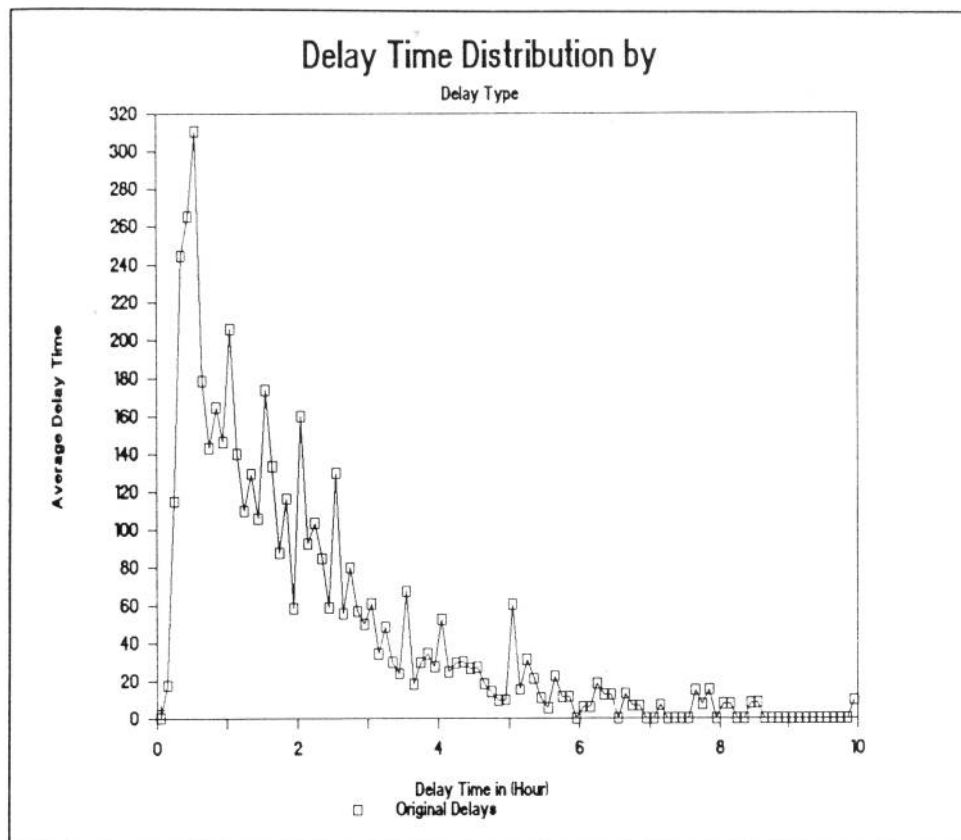


Figure 3-16

The major reactionary delays are late arrivals from previous technical delays representing 66% of reactionary delays and 71% of reactionary delay times, the second highest in frequencies is late arrivals from previous marketing delays representing 10% of delays and 6% of total reactionary delay times.

The third highest in delay time is late arrival from previous weather delays representing 14% of total delay times and 8% of delay frequencies.

Figure 3-17 illustrates the reactionary delay frequency distribution function with mean 1.16 hours and 1.40 hours variance. Peak delay time is around 200 delays for a group of three delay times between 24-36 minutes. **Figure 3.18** shows the reactionary delay time distribution function.

c) **Connection Delays:**

The third type of delays are due to flight connections which represent minimal percentages of the general delays. 3% of the general delays are the connection delays and 2% of the general delay time. This type of

delay is represented by delay code number 16 "connections" only. The mean is 0.69 hours and 0.84 hours variance.

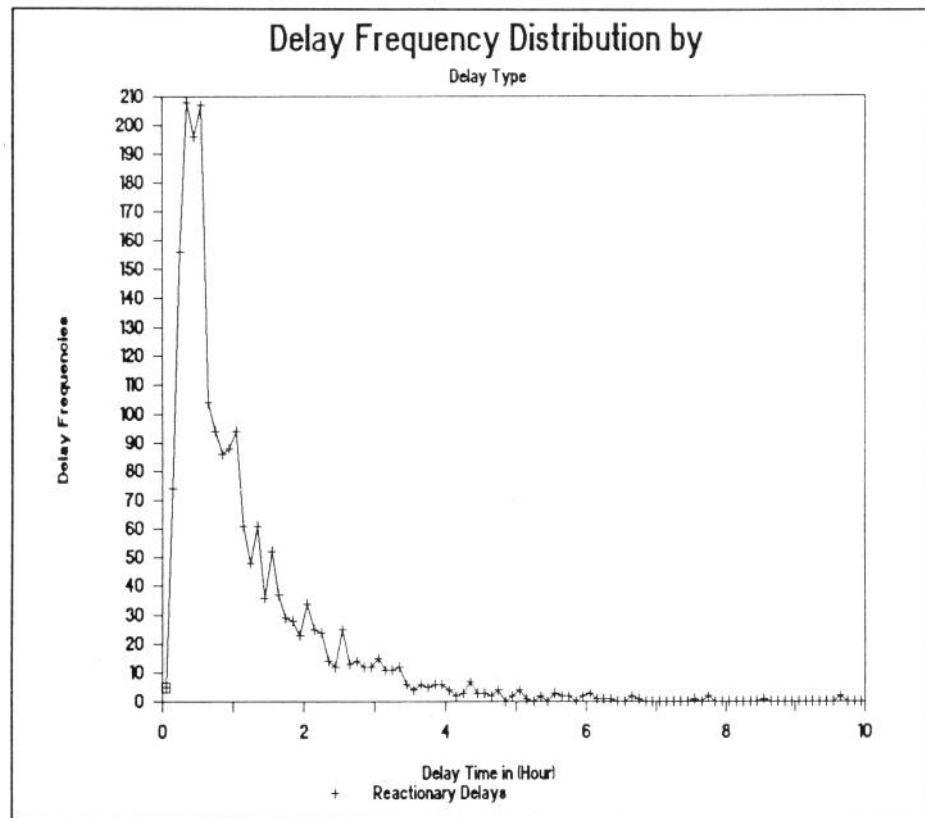


Figure 3-17

Delays due to connections represent small percentages of general delays and delay times (2% and 3% respectively). This delay type is a function of the schedule and the amount of flights connections build in the schedules. For example, if airline considers the Hub and Spoke concepts in development of schedule, the number of flight connections will increase which will affect this delay type more and consequently will increase the delay frequency and delay time.

Figure 3.19 shows the delay frequency distribution for connections with peak of 50 delays at a mode of 0.33 hours.

Figure 3.20 the delay time distribution for connection delays with a peak of 20 hours delays at the mode.

d) Other Delays:

This is the fourth type of delay which involves other delay codes not applicable in any of the first three delay types such as pending, time lost enroute, time gained enroute and indirect delays. This delay type represents 10% of the general delay distribution and 7% of the general delay time distribution. The major codes in this type are pending delays due to internal dispute of delay coding and time lost enroute delay causing 48% and 51% of this delay type respectively.

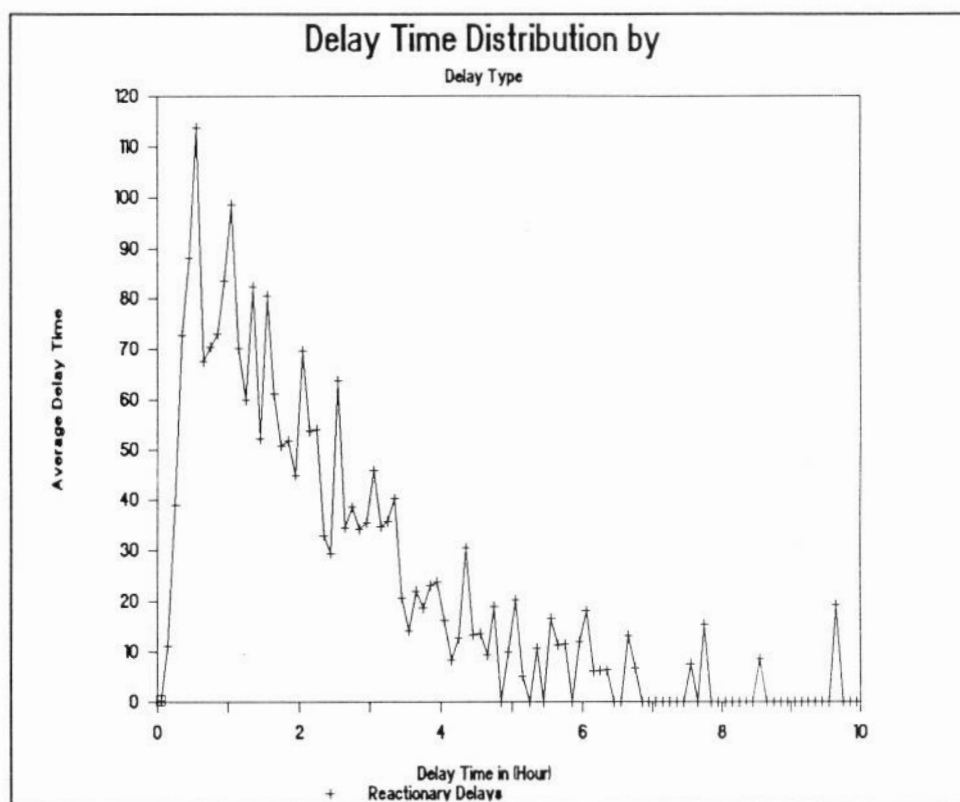


Figure 3-18

Figure 3.19 shows also the delay frequency distribution for other delays type with mean of 0.63 hour and 0.86 variance.

Figure 3.20 shows also the delay time frequency distribution. 'Time Lost Enroute' delay is the major delay in this delay type due to its effect to the block times in which it represents 38% of delay frequency and 51% of delay time. Mean of time lost enroute is 0.47 hours with 0.77 hour variance.

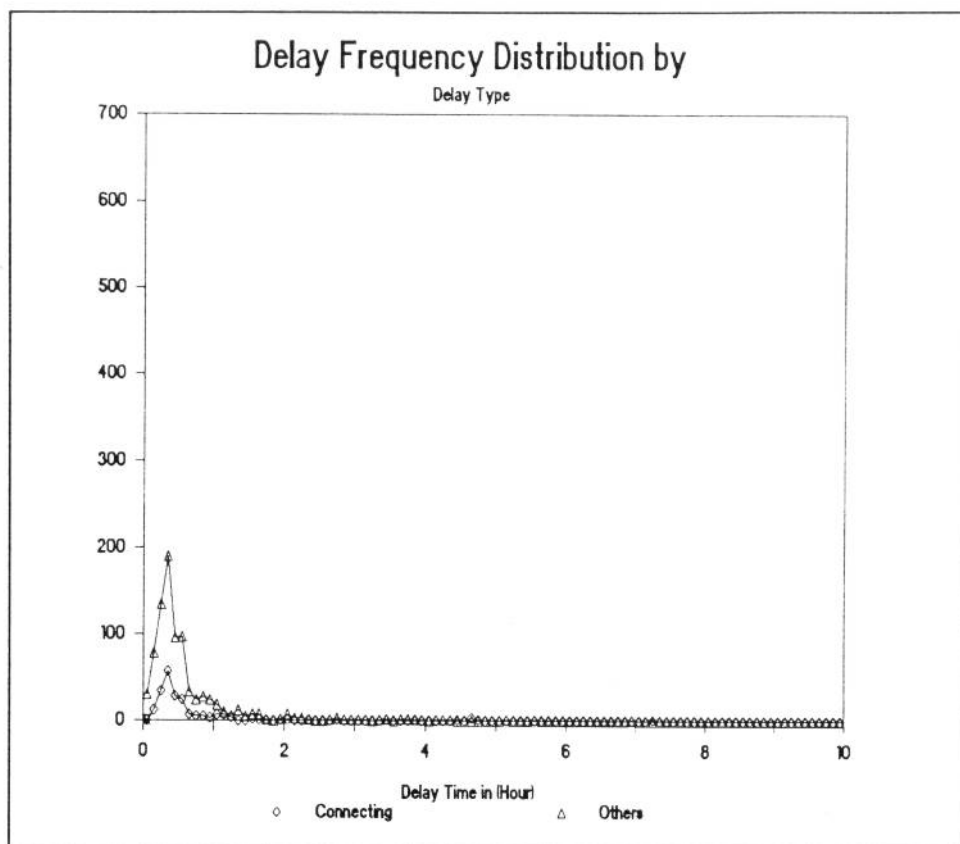


Figure 3-19

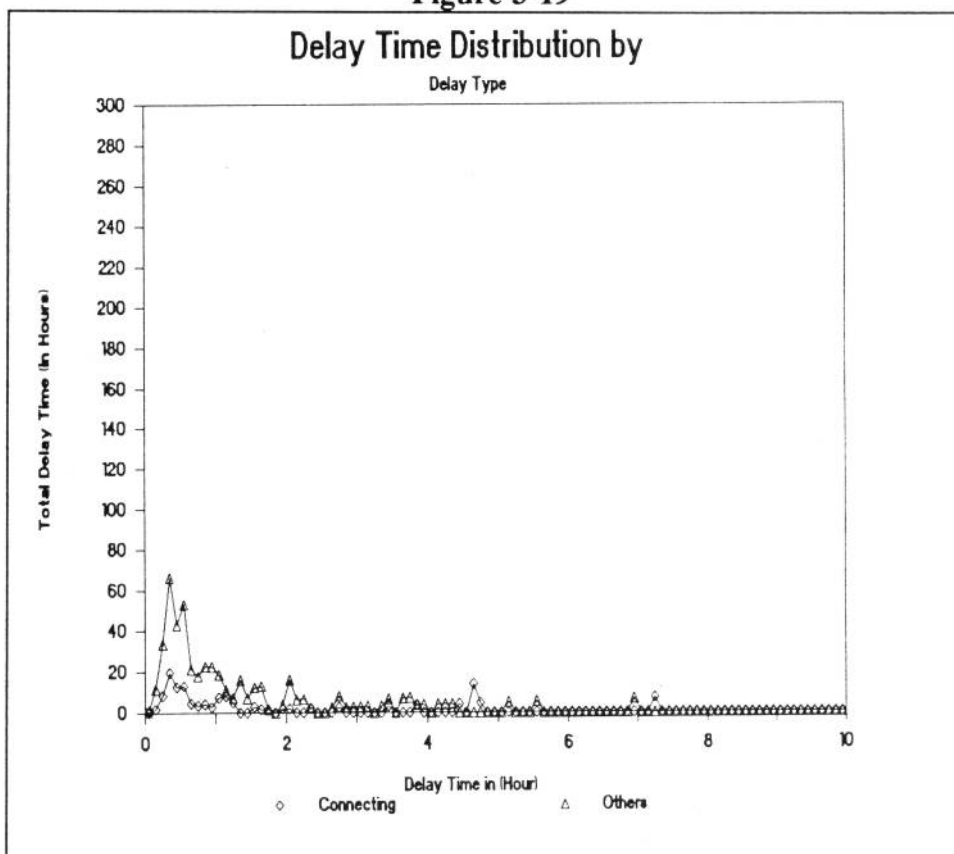


Figure 3-20

3.6 DELAYS ANALYSIS OF VARIANCE:

Analysis of variance comparison is applied for means of delay types, the null hypotheses is "all delay types means are equals". **Table 3-3** is an extract from the output with statistics on different delay types and confidence intervals on means. It shows that means of delay type are different and the null hypotheses is rejected.

Table 3-3

<u>Delay Type</u>	<u>Mean</u>	<u>Std Dev</u>	<u>95% Int.</u>	<u>for</u>	<u>Conf. Mean</u>
Original	0.993	1.035	0.963	to	1.022
Reactionary	1.161	1.185	1.109	to	1.213
Connection	0.690	0.917	0.565	to	0.815
others	0.634	0.925	0.571	to	0.696
Total:	0.989	1.073	0.965	to	1.013

Multiple Range Test is applied to determine the pairs of delay groups which are significantly different from others and **Scheffe procedure test** is applied. There are two methods for multiple comparison one is Tukey's method and the second is Scheffe's method. " The main restriction on Tukey's method is that it requires equal sample sizes. In some controlled applications managers can guarantee equal sample sizes from each population. However in many other applications equal sample sizes are not possible. When decision makers have unequal sample sizes, the analysis of variance equations still apply, as does the interpretation of results. But, since Tukey's does not apply, decision makers need a method of multiple comparisons that allows unequal sample sizes. Henry Scheffe has developed such a procedure". (GROEBNER AND SHANNON (54)). Because of different sample sizes in the delay types this method is applied. It concludes that at 0.05 level the delay type has the following groups:

Group one	:	Original Delays
Group two	:	Reactionary Delays
Group Three	:	Connecting and other delays

As a result of this analysis and multiple range comparison, three groups are significant groups which have three different features. *Group one* contains original delays with 95 Confidence Interval of mean from 0.96 to 1.02. *Group*

two contains Reactionary delays which have 95 Confidence Interval of mean of 1.1 to 1.21 and *group three* has connections and other delays which have a range of mean interval from 0.565 to 0.815 and 0.571 to 0.696 from connections and others respectively.

3.7 RELATIONSHIP BETWEEN ORIGINAL AND REACTIONARY DELAYS:

The relationship between original delay and reactionary delay is dependent on schedule development and other factors mentioned earlier in chapter 1 and chapter 2. The purpose here is to recognize the relationship in this sample data.

Figure 3-21 illustrates pictorially the delay frequency distribution functions for the original and reactionary delays. For delays within one hour delay time, reactionary delays are much less than original delays. This is because in most of the delay cases original delays is overcome quickly before it is propagated in the schedule. This is accomplished through different ways either through absorbing it in the ground time or in the flight time.

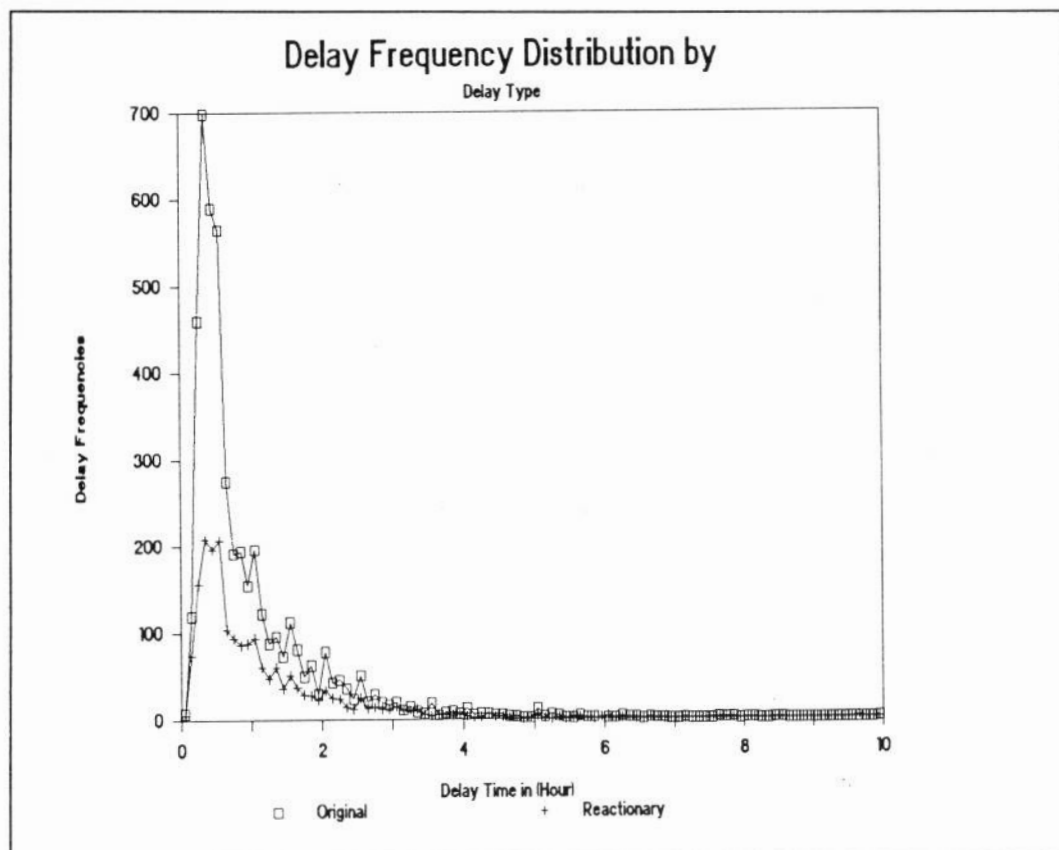


Figure 3-21

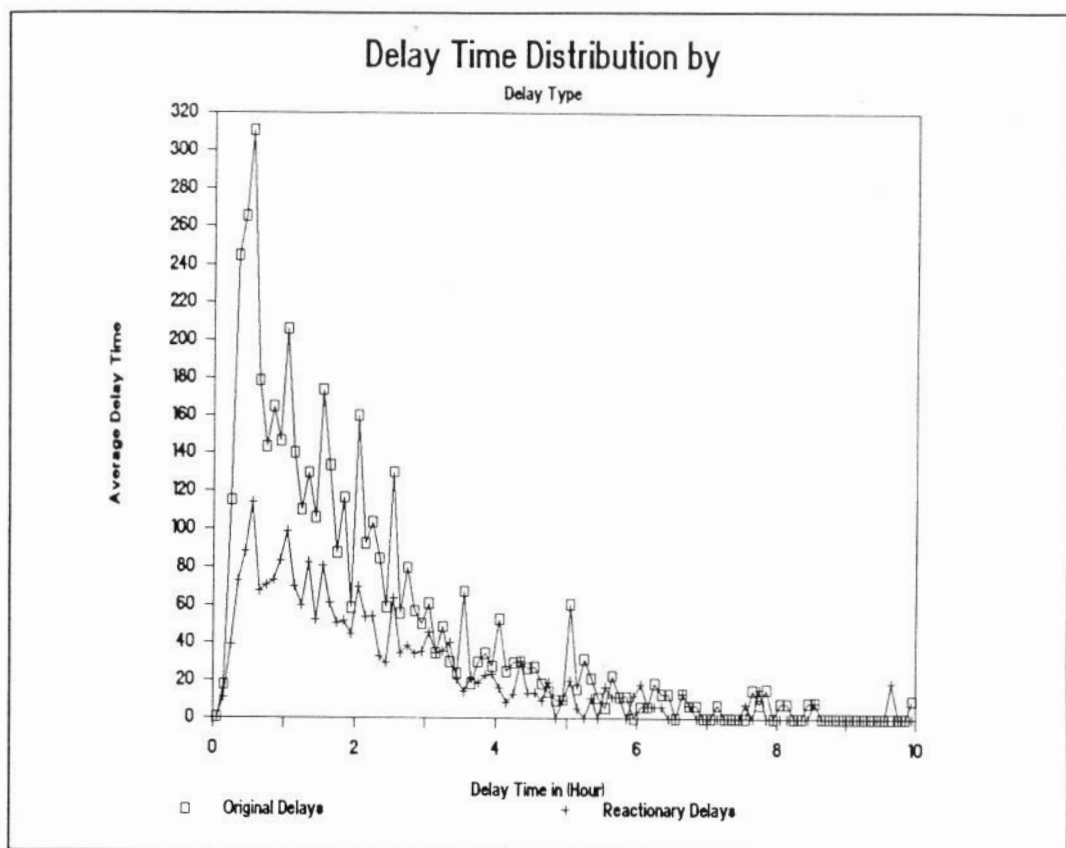


Figure 3-22

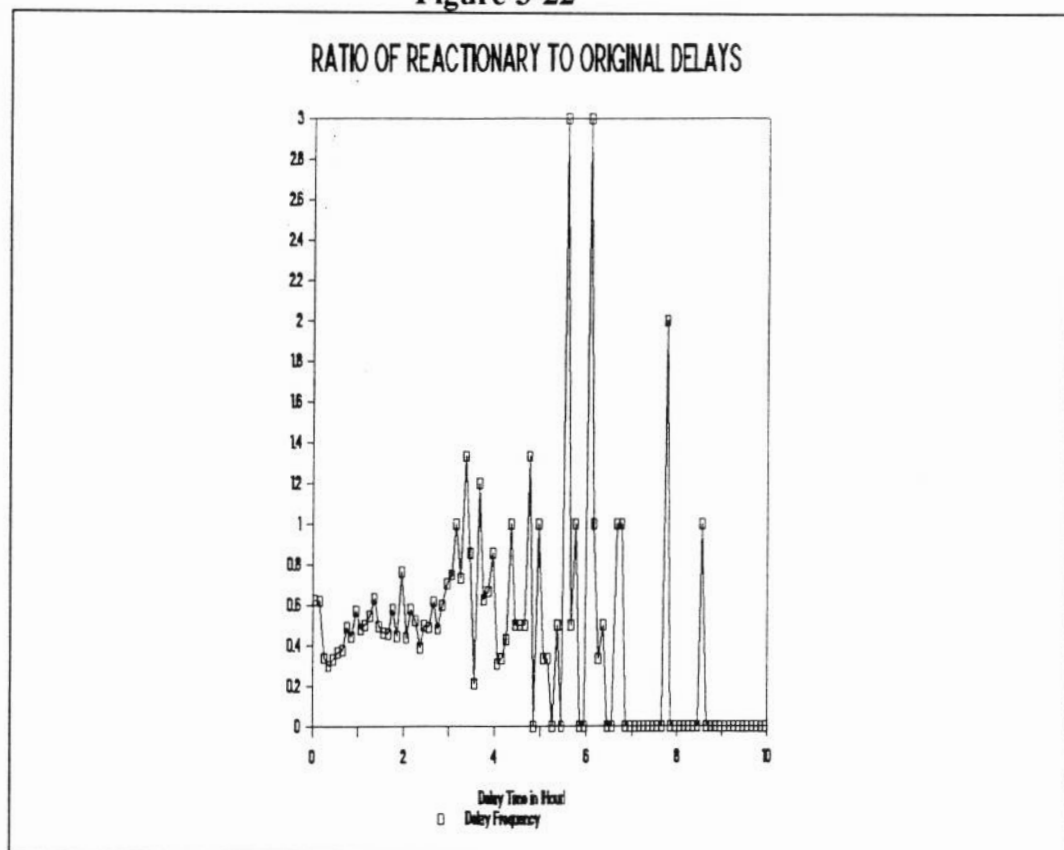


Figure 3-23

Figure 3-22 shows the comparison between original delays and reactionary delay time distribution functions. The same conclusion derived from the previous graph is applicable here but the variations in delay time are more.

In figure 3-23 illustrates the ratio of reactionary delay frequencies (delay type two) which are propagated from original delay frequencies (delay type one) is derived for an interval of delay time in hours.

It is noticeable from the graph that original delays which are more than five hours delay duration have a large reactionary delay duration but the frequency are very low as appears in figure (3-21).

A grouping of the delay time into larger intervals gives better visualization of figure (3-23). Figure 3-24 shows the ratio of reactionary to original delay frequencies within one hour delay interval including elimination of the extreme data elements shown in figure (3-23). The extreme data elements which are dropped are grouped in one hour delay time interval to identify a more significant conclusion from the modified graph. The data dropped represents 3% of the total delays.

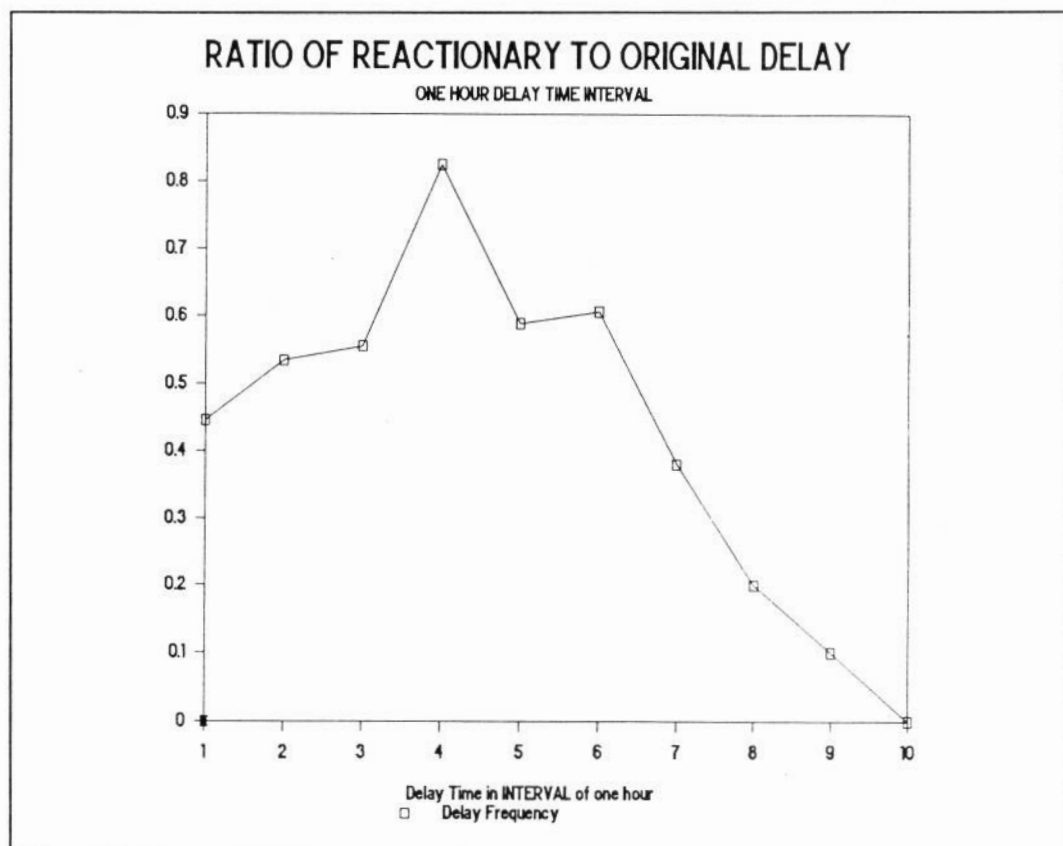


Figure 3-24

<u>Delay Time Duration (in Hr)</u>	<u>Ratio of Reactionary to Original Delays</u>
0.01 - 1.00	0.45
1.01 - 2.00	0.54
2.01 - 3.00	0.56
3.01 - 4.00	0.83
4.01 - 5.00	0.59
5.01 - 6.00	0.61
6.01 - 7.00	0.38
7.01 - 8.00	0.20
8.01 - 9.00	0.10
9.01 - 10.0	0.00

As shown in that graph, original delays which have delay durations within one to six hours are propagated in the schedule as reactionary delays with a ratio vary from 0.40 to 0.60 of the original delays, **except** for delay duration of four hours where the ratio is 0.83 of original delays. Delay durations more than six hours the propagation decreases and approaches zero at 10 hours delay durations. This minimal reactionary delay is due to diversion of other aircraft types to the disturbed flights made as a result to correct delays. While with 3-4 hours delays, there is not enough time to divert other aircraft or send a spare unit so in most cases the same aircraft is kept especially if it is maintainable and due to operational constraints or delay duration.

3.8 CONCLUSION:

15% the total flights are disturbed flights (9% delays and 6% cancellations). 8.5% of total departures are delayed flights for more than 15 minutes delay.

Delays are classified into four types of delays. Original delays representing 61% of the general delays, reactionary delays representing 26% of the general delays, connection delays representing 3% and others 10%.

Three groups are significant groups from the four delay types of the general delays which have three different features as a result of ANOVA comparison test. Group one contains original delays with 95% confidence interval of mean from 0.96 to 1.02. Group two contains reactionary delays which have 95% confidence interval of mean of 1.1 to 1.21 and group three has connections and other delays which have a range of mean interval from 0.565 to 0.815 and 0.571 to 0.696 with 95% confidence interval for connections and others respectively. The average ratio of reactionary delays to original delays is between 0.40 to 0.60.

Chapter (4)

Estimation of Delays Distributions

Many delay distributions were developed in the previous chapter "delay analysis". The objective of this chapter is to estimate the best representative statistical distribution for future applications.

Estimation objectives and difficulties are introduced in section 4.1. The background on suitable synthetic reliability distributions functions including **lognormal and Weibull** is presented in section 4.2. It includes a definition of probability distribution function, means, variances and major characteristics of the distribution functions. Section 4.3 discusses the approach and formulae used for the estimation of *lognormal distribution* sample parameters and section 4.4 discusses the same for estimation of the *Weibull distribution*.

Section 4.5 discusses the estimation of the **general delay distribution** found in chapter 3 using lognormal and Weibull estimates with some graphs illustrating the quality of estimation and estimation error. Section 4.6 estimates the **original delay distribution** using lognormal and Weibull distribution functions estimates. Section 4.7 estimates the **reactionary delay distribution**. Section 4.8 discusses the **general delay distributions Comparison** including the goodness of fit and then conclusions are summarized in section 4.9.

4.1 Introduction:

As previously shown in chapter 3 "Delays Analysis", many delay distributions are developed for different categories of delay codes and for different types of delays. Delays can also be analyzed by type of aircraft, month of delay to discover existence of seasonality or other factors and region or station where delay takes place.

The purpose of using synthetic delay distributions is the ease of modeling of delay distribution functions in the forecasting of future delays and using them as an input to aircraft rotation, **schedule simulation models** and estimates of reliability.

The major common synthetic reliability distributions used in reliability research are *lognormal distribution and Weibull distribution* which both estimate the

general and original delay frequency. Delay time distributions are discussed and graphically presented.

Figure 4-1 shows the general delay frequency distribution function which was analyzed previously in chapter 3.

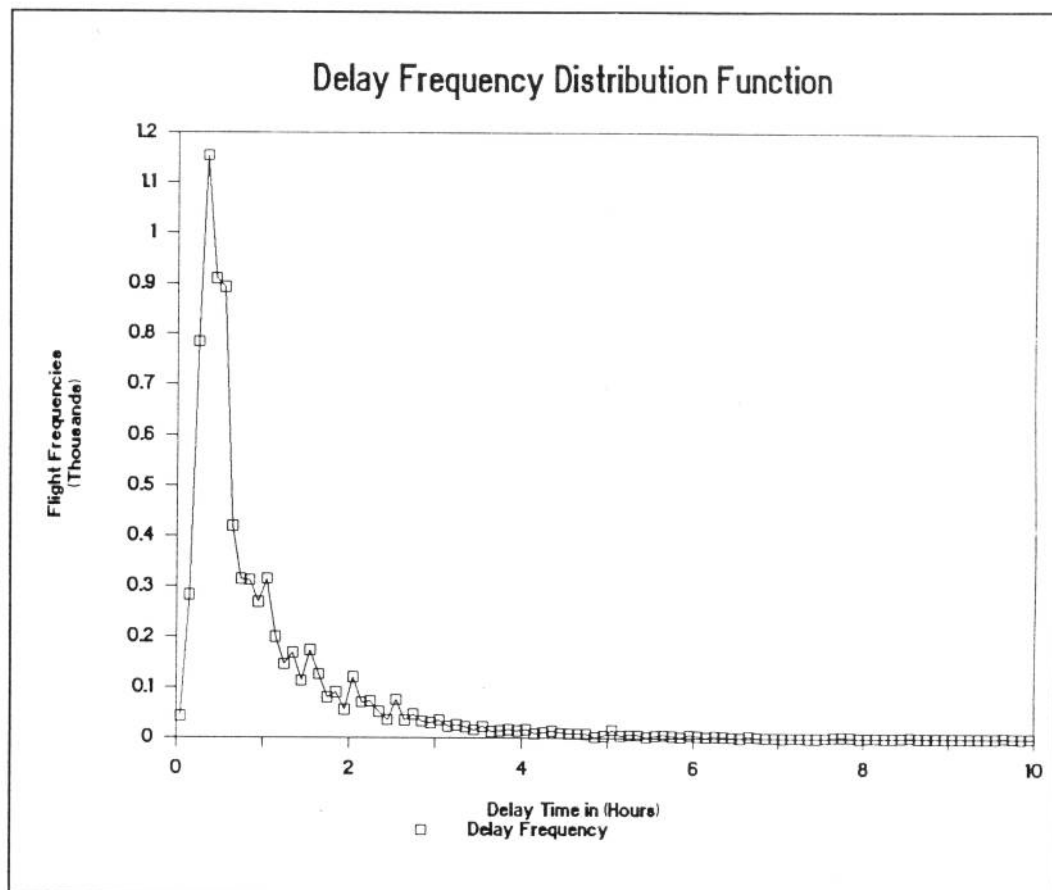


Figure 4-1 General delay frequency distribution

4.2 Overview of Synthetic Distributions:

This overview of lognormal and Weibull probability distribution functions includes basic definition of probability density function, mean, variance, major characteristics and special cases (WAIPOLE AND MYERS (55)).

(a) Log normal Distribution:

The lognormal density function is defined as

$$f(t) = \frac{1}{\sigma t \sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{\ln t - \mu}{\sigma} \right)^2 \right], \quad t \geq 0 \quad (1)$$

where μ and σ are parameters such that $-\infty < \mu < \infty$ and $\sigma > 0$ and t is the time. Various forms of the lognormal density function are illustrated in figure 4-2.

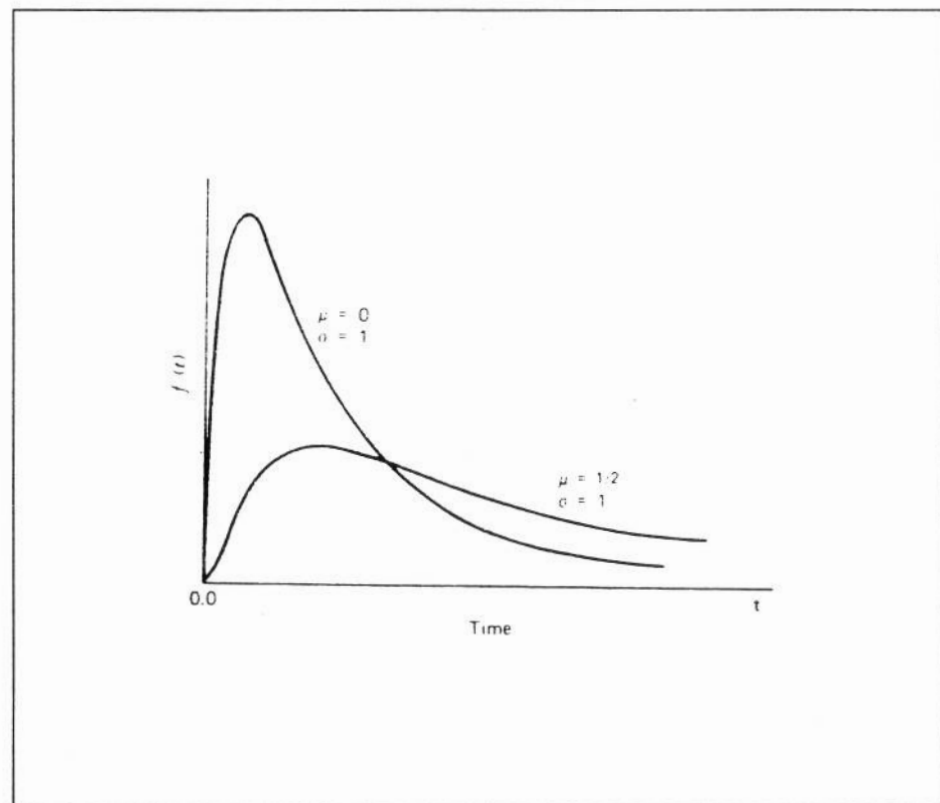


Figure 4-2 Forms of lognormal density function.

If a random variable x is defined as $x = \ln t$, and x is normally distributed with a mean of μ and standard deviation σ then,

$$E(x) = E(\ln t) = \mu$$

and

$$V(x) = V(\ln t) = \sigma^2$$

Since $t = e^x$, and after mathematical derivation the mean and variance of lognormal distribution (t) are (56) :

$$\text{Mean} = \exp \left[\mu + \frac{\sigma^2}{2} \right] \quad (2)$$

$$\text{Variance} = \left[e^{2\mu + 2\sigma^2} \right] \left[e^{\sigma^2} - 1 \right] \quad (3)$$

(b) **Weibull Distribution:**

The probability density function for Weibull distribution is defined as

$$f(t) = \frac{\beta (t - \delta)^{\beta-1}}{(\theta - \delta)^\beta} \exp \left[- \left(\frac{t - \delta}{\theta - \delta} \right)^\beta \right] \quad (4)$$

where

t = time

β = shape parameters

θ, δ = scale parameters, all positive.

Figure 4-3 shows different forms of Weibull distribution functions with different values for θ , and β .

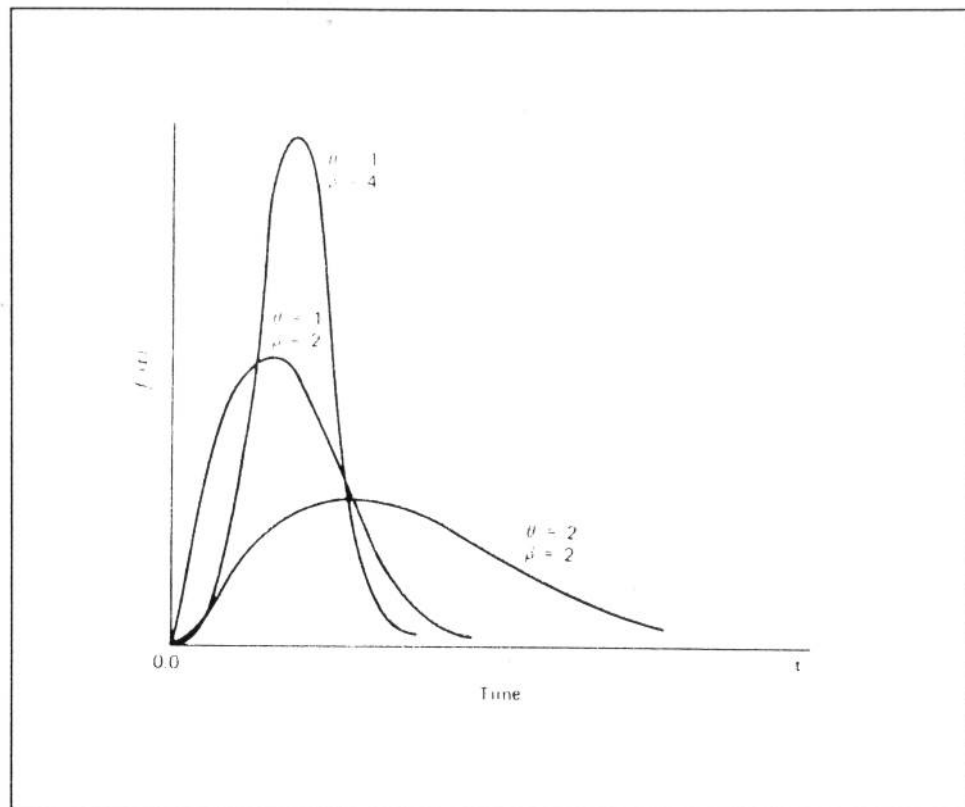


Figure 4-3 Forms of Weibull density function.

4.3 Estimation of Lognormal Distribution Parameters:

With reference to the mean and variance of lognormal distribution presented in the previous section, the following analytical estimation of distribution parameters are developed:

The mean of sample data is defined here as (M) and Variance is (V) where *estimate of mean* for lognormal distribution function is (μ) and *estimate of variance* is (σ^2). Then

$$M = \exp \left[\mu + \frac{\sigma^2}{2} \right]$$

$$M = \exp [\mu + 0.5(\sigma^2)] \quad (5)$$

$$V = [\exp (2\mu + \sigma^2)] [\exp (\sigma^2) - 1] \quad (6)$$

By squaring equation (5) then;

$$\begin{aligned}
 M^2 &= [\exp \{ \mu + 0.5(\sigma^2) \}]^2 \\
 &= \exp [2\{ \mu + 0.5(\sigma^2) \}] \\
 &= \exp [2\mu + \sigma^2]
 \end{aligned} \tag{7}$$

Equation (7) is equivalent to the first term of equation.(6). Then equation (6) will be ;

$$V = M^2 [\exp (\sigma^2) - 1]$$

divide both sides by M^2 , then

$$V/M^2 = \exp (\sigma^2) - 1$$

$$(V/M^2) + 1 = \exp (\sigma^2)$$

$$\ln \{(V/M^2) + 1\} = \sigma^2 \tag{8}$$

Then the **estimation approach** is straightforward knowing the sample value of mean (M) and variance (V), solve equations (5) or (7) and equation (8) then the estimated lognormal distribution parameters values μ and σ are found.

Estimation of general delay distribution:

This subsection demonstrates the estimation approach of lognormal distribution parameters for general delay distribution function discussed in the previous chapter. As developed earlier the general delay distribution function has mean = 0.989 and variance = 1.150. Figure 4-1 shows the actual general delay frequency distribution function.

By substituting sample values of mean and variance in equation (8) and equation (5). Equation (8) will be:

$$\begin{aligned}
 \sigma^2 &= \ln \{(V/M^2) + 1\} \\
 &= \ln \{(1.15/0.972) + 1\}
 \end{aligned}$$

$$= 0.7778$$

Then

$$\sigma = 0.8819$$

By substituting in equation (5):

$$M = \exp \{ \mu + 0.5(\sigma^2) \}$$

$$0.989 = \exp \{ \mu + 0.5(0.7778) \}$$

$$0.989 = \exp (\mu + 0.3889)$$

$$0.989 = \exp (\mu) \cdot \exp (0.3889)$$

$$\exp (\mu) = 0.67035$$

Then

$$\mu = -0.3999$$

Now μ and σ , estimate of the general delay frequency distribution for a lognormal distribution function is $\mu = -0.3999$ and $\sigma = 0.8819$. Using these values in the general definition of lognormal density function equation (1) to generate the estimated distribution function for general delay function. **Figure 4-4** illustrates the estimated lognormal function.

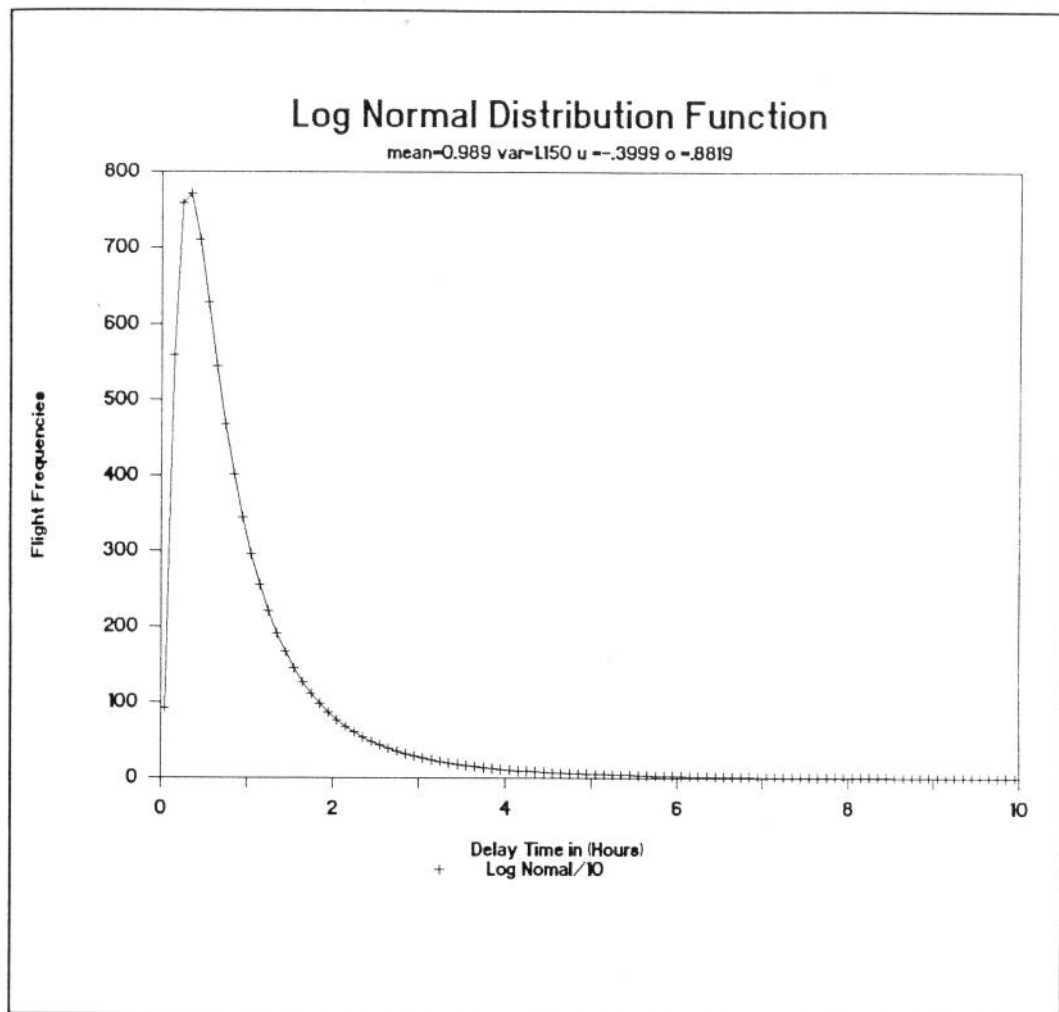


Figure 4-4 The estimated lognormal distribution function

4.4 Estimation of Weibull Distribution Parameter:

Weibull Probability Density Function is defined in terms of its parameters β , and θ as appears in equation (4). The following definition is a function of parameters a_1 , a_2 and a_3 as defined by (SEN and PRABHASHANKER (57)).

$$f(x) = (a_1 - a_2) \left\{ \frac{(x - a_3)}{a_2} \right\}^{a_1 - 1} \exp \left[- \left\{ \frac{(x - a_3)}{a_2} \right\}^{a_1} \right] \quad (11)$$

where

a_1 = shape parameters,

a_2 = scale parameters,

a_3 = Location parameter.

$f(x)$ is valid for a_1 and $a_2 > 0$ and $f(x)=0$ if $x < a_3$.

Estimating the population parameters from the sample data for many distributions could be quite tedious. In many cases the maximum likelihood (ML) estimates provide more efficient estimates than the simple method of moments (MM). However, the method of moments could be useful and preferable under certain conditions. This is particularly true for certain ranges of the parameter values in case of the Weibull distribution.

The use of ML estimates was generally avoided by engineers until recently, as it results in a system of non-linear equations not easy to solve. The situation is further complicated by the intrinsic constraints imposed on the parameters. Considerable difficulty is encountered in fitting Weibull distribution and there are suggested methods for parameter estimations (SEN AND PRABHASHANKER (57)).

The Weibull distribution parameters cannot be expressed in terms of the lower moments by simple functions. SEN AND PRABHASHANKER (57) developed a simple nomograph from which the three parameters could be estimated with reasonable accuracy based on the method of moments. Though as not efficient as ML estimates but as demonstrated by SEN AND PRABHASHANKER many cases the nomograph is quite adequate. **Figure 4-5** shows the nomograph used for the estimation of a sample Weibull distribution function with the three parameters a_1 , a_2 and a_3 . Two horizontal scales 1a and 1b are shown on the nomograph. **Figure 4-5** shows two nomographs for different scales, 1a and 1b are used by the sample estimate of the third moment (m_3) which is $(B_1^{0.5})$. Curves 3a and 3b are used to locate the sample standard deviation (σ). 3a is used with 1a and 3b is used with 1b according to the initial values. There are five vertical scales, 2a, 2b, 4, 5 and 6. Scale 2a will give estimate a_1 , scale 6 will give estimate a_2 and scale 5 will give estimate m_1 - a_3 .

A detailed approach of determining the three parameters is explained in appendix B of this research with examples. The method of nomograph construction is explained with the mathematical background in the appendix of the SEN and PRABHASHANKER reference.

In order to verify the closeness of the estimates obtained with the nomograph and the empirical procedure, SEN and PRABHASHANKER demonstrate that with examples. Table 4-1 illustrates the parameters estimates values developed by the maximum likelihood, empirical procedure and nomograph. The estimates for HARTER and MOORE (58), a Weibull sample was generated by them from a population with parameters:

$$a1 = 3.0, \quad a2 = 100.0 \quad \text{and} \quad a3 = 20.0.$$

The sample estimate of $\beta^{.5}$, σ and μ are

$$\beta^{.5} = 0.3533, \quad \sigma = 34.18 \quad \mu = 104.8.$$

Then after applying the procedure for estimation using nomograph,

$$a1 = 2.525, \quad a2 = 91.0 \quad \text{and} \quad a3 = 24.3.$$

Table 4-1 Weibull estimated parameters

<u>parameter</u>	<u>population value</u>	<u>Maximum likelihood</u>	<u>Nomograph estimates</u>	<u>Empirical estimates</u>
a1	3.000	2.330	2.525	2.526
a2	100.0	83.50	91.00	90.84
a3	20.00	30.80	24.30	24.19

The goodness of fit test values (Chi square test) for the three approaches as follows; 7.6 (nomograph), 5.2 (maximum likelihood) and 7.6 are (empirical procedure) while the critical value for chi square at 0.05 level of significance and for 4 degrees of freedom is 9.49.

Table 4-2 defines the ranges for the nomograph parameters and its scales which belong to these parameters.

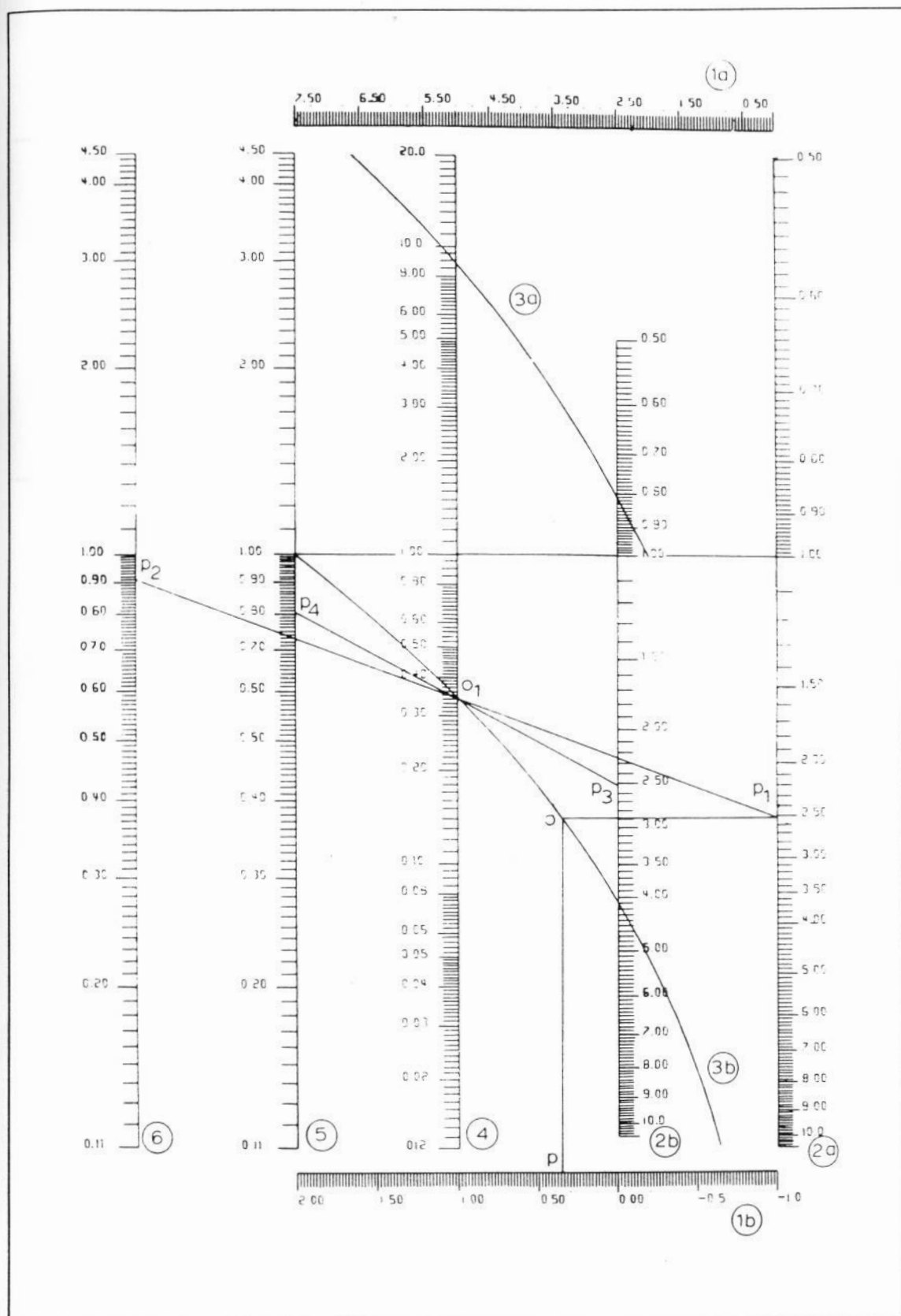


Figure 4-5 Nomograph for estimating Weibull distribution function, three parameters (a_1 , a_2 and a_3)

Table 4-2 The nomograph scale

Scale	Parameter	Range
1a	$\beta 1^{.5}$	$2.00 \leq \beta 1.5 \leq 7.50$
1b	$\beta 1^{.5}$	$-.66 \leq \beta 1.5 \leq 2.00$
2a	a1	$0.50 \leq a1 \leq 10.50$
2b	a1	$0.50 \leq a1 \leq 10.50$
4	o	$0.012 \leq o \leq 20.000$
5	u-a3	$0.110 \leq (u1-a3) \leq 4.5$
6	a2	$0.110 \leq a2 \leq 4.500$

The **estimation approach** focuses on estimating the three parameters values a1, a2 and a3. To determine these values, the sample estimate of the standardized third moment ($(\beta 1)^{0.5}$), sample standard deviation (σ) and sample mean (μ) have to be evaluated and used as the starting points in the nomograph. Then the distribution parameters are updated and the fitting accuracy determined by calculating the error and error percentage for the actual distribution. Starting points are defined as follows:

μ = Sample Mean

σ = Sample standard deviation

$(\beta 1)^{0.5}$ = Sample estimate of the standardized third moment.

The mathematical derivation of these sample parameters are defined as :

$$\mu = d + b m_1 ,$$

where

b = the interval,

d = the most popular frequency interval,

m_1 is the first moment around the mean

$$\sigma = \{b^2 (m_2 - m_1)^2\}^{0.5},$$

$$\text{and } (\beta 1)^{0.5} = (m_3 / m_2)^{1.5}$$

where generally,

m_r = The r th moment around the mean

$$m_r = [\sum \{f_i (Z_i)^r\}] / n$$

where

$$Z_i = (x_i - d)/b$$

Estimation of general delay distribution:

The purpose is to demonstrate the approach for the estimation of general delay frequency distribution as Weibull distribution function. It appears in figure 4-1 the general delay frequency distribution function with mean = 0.989 and variance = 1.15. The three sample parameters (μ , σ and $(\beta 1)^{0.5}$) are calculated according to the formulas defined earlier by means of Lotus 123 spreadsheet. The following are the values determined:

$$\mu = 0.9855$$

$$\sigma = 1.0309$$

$$(\beta 1)^{0.5} = 6.6571$$

Using these parameters to determine the three Weibull parameter a_1 , a_2 and a_3 from the nomograph the results appears in Figure 4-5. A procedure for estimating the Weibull parameters from the nomograph is explained in appendix B.

These values are used as a basis for an iterative procedure in fitting the distribution by numerical monitoring of the error and percentage error from the actual distribution. This is one of the expectations from using the nomograph as concluded by SEN (57). As mentioned earlier in this section, finding the

synthetic distribution is a lengthy activity, the estimated parameters formulated by SEN and PRABHASHANKER a_1 , a_2 and a_3 could not be reflected easily in the distribution. In other words when actual updating values for scale or location the PROBABILITY DISTRIBUTION FUNCTION changes its shape rather than changing its scale or location.

However, after a number of iterations the parameters of Weibull distribution function are estimated as follows:

$$\begin{array}{lll} a_1 & = & 0.75 \\ a_2 & = & 0.75 \\ a_3 & = & 0.05 \\ \sigma & = & 0.9855 \\ \mu & = & 1.039 \end{array}$$

As a result of using the nomograph it is difficult to find appropriate estimates, the nomograph in this case give only the starting points. Then many experimentations are performed with the three parameters until a reasonable fit is found.

4.5 General Delay Distribution Estimation:

This section explains the distribution estimation of the general delay frequency distribution which was subject to analysis in chapter (3). Estimation including fitting *lognormal* and *Weibull* distribution functions and error of estimation.

(a) Lognormal Distribution Estimation:

Figure 4-6 shows the general delay function with mean = 0.989 and variance = 1.150 and the estimated lognormal distribution function with the estimated parameters $\mu = -0.3999$ and $\sigma = 0.8819$.

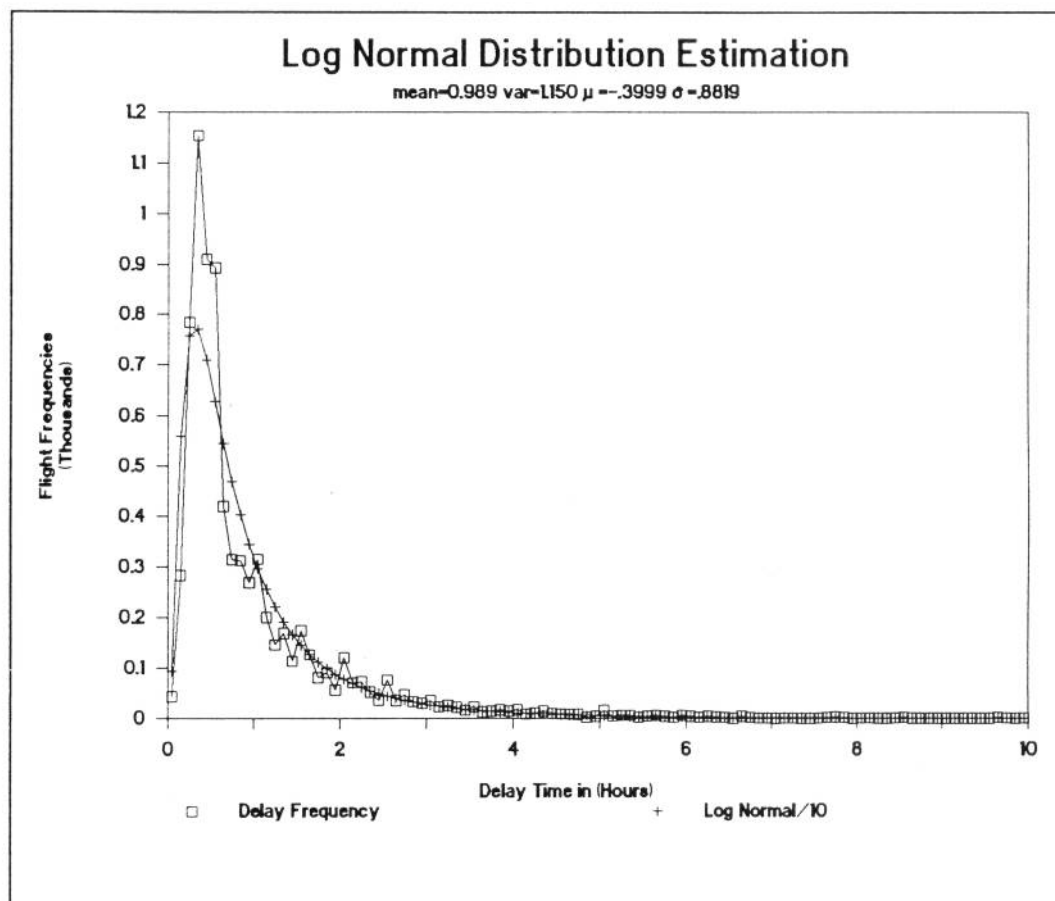


Figure 4-6 General delay and lognormal distributions

Figure 4-7 illustrates the same graph but with x axis scale for only the first five hours delay time duration. It is noted from the graph that delay observations are minimal for five hours and more.

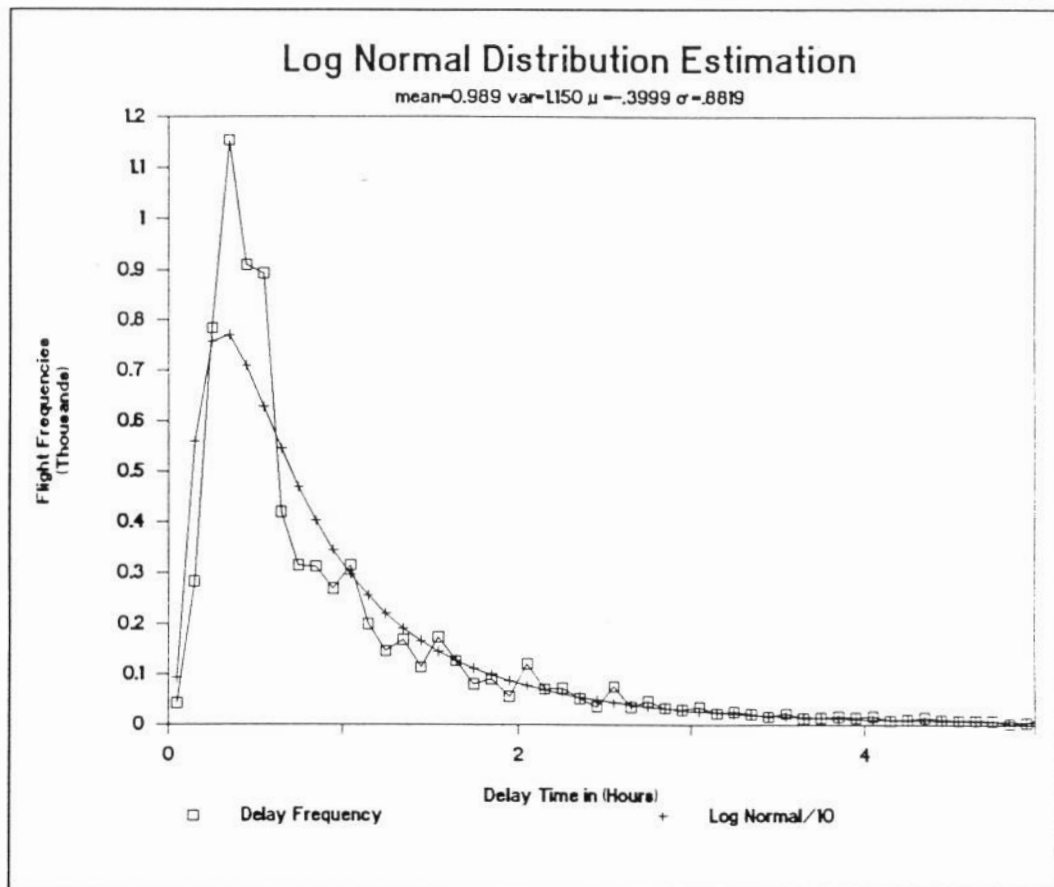


Figure 4-7 General delay and lognormal distributions

Figure 4-8 shows the error between the general delay and the estimated lognormal distribution. As observed there is a large error for the first hour delay time range which varies between - 300 to + 300 flights delay. Specifically for a twelve minutes delay time, the delay error is - 300 delays and for 24 minutes delay time, the error is about 400 delays.

Error percentage varies in interval $\pm 60\%$ as shown in **figure 4-9** for the first half hour the error percentage decreases until reaches 20% to 25% up to two hours delay time then it even decreases after that except for some points.

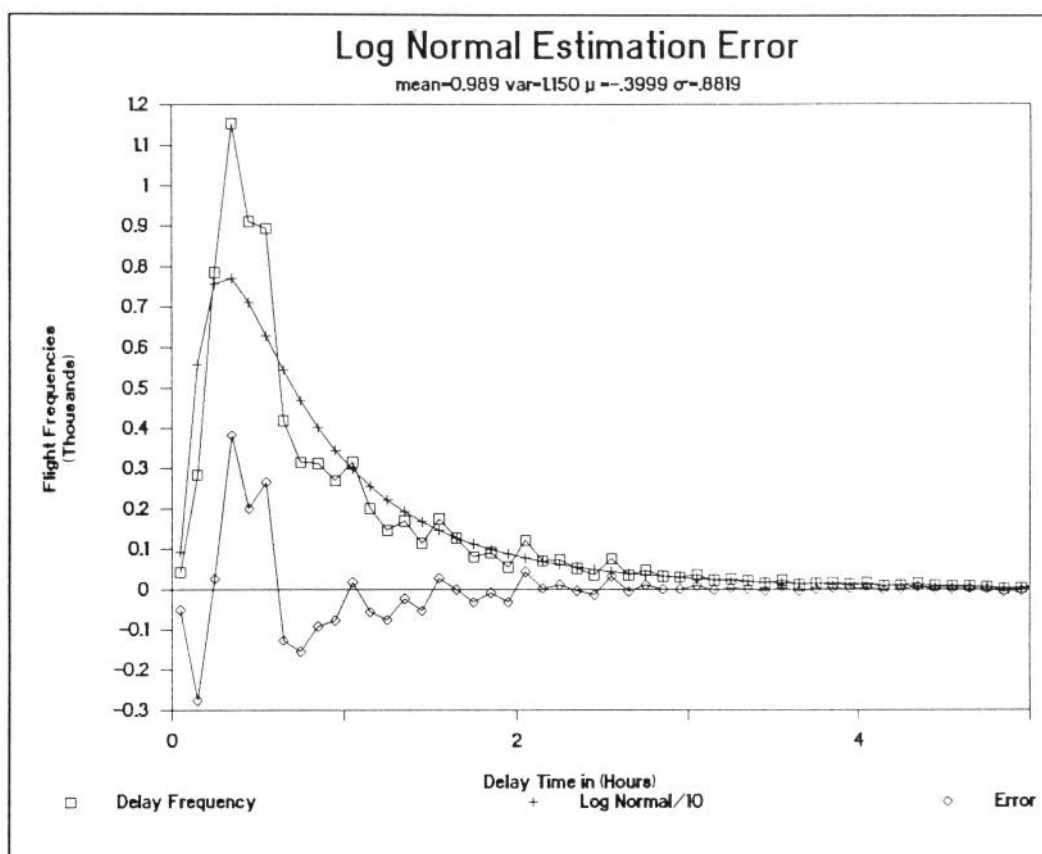


Figure 4-8 Estimation error

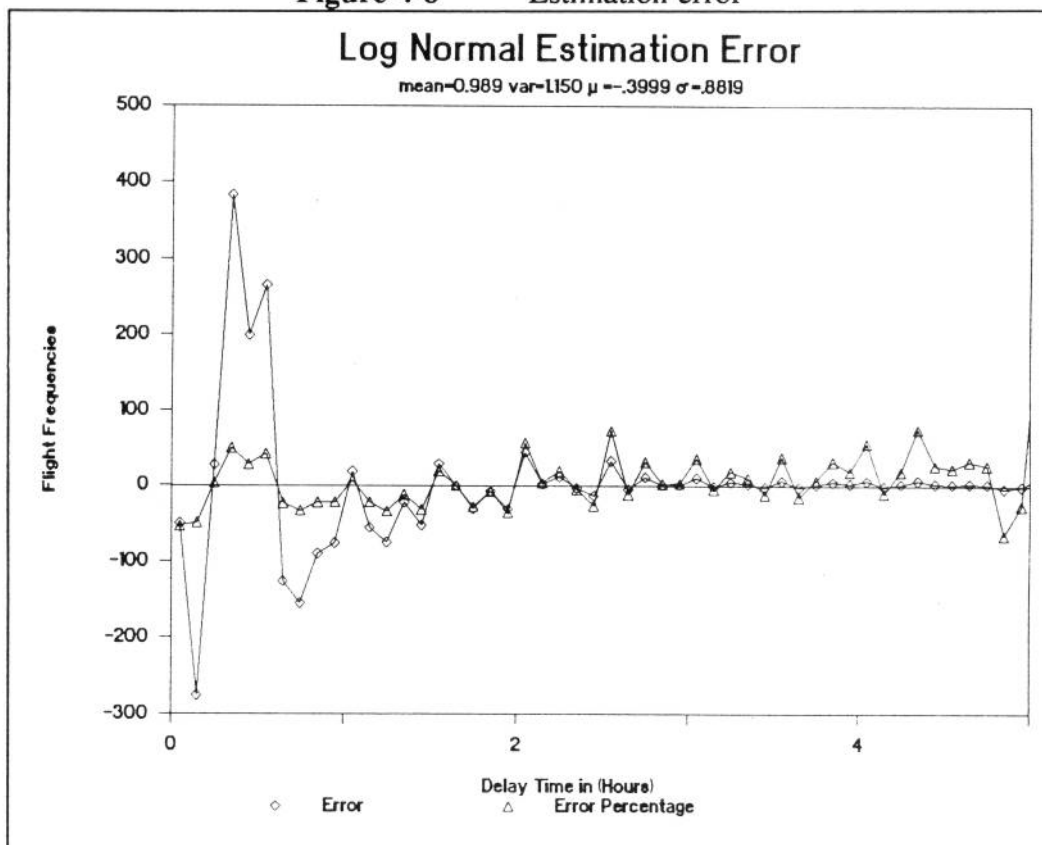


Figure 4-8 Estimation error

Delay time error and delay frequency error appears in **figure 4-10** Although for 12 minutes delay the error is -300 delays but time error is -50 hours and 150 hours for delay time between 24-30 minutes.

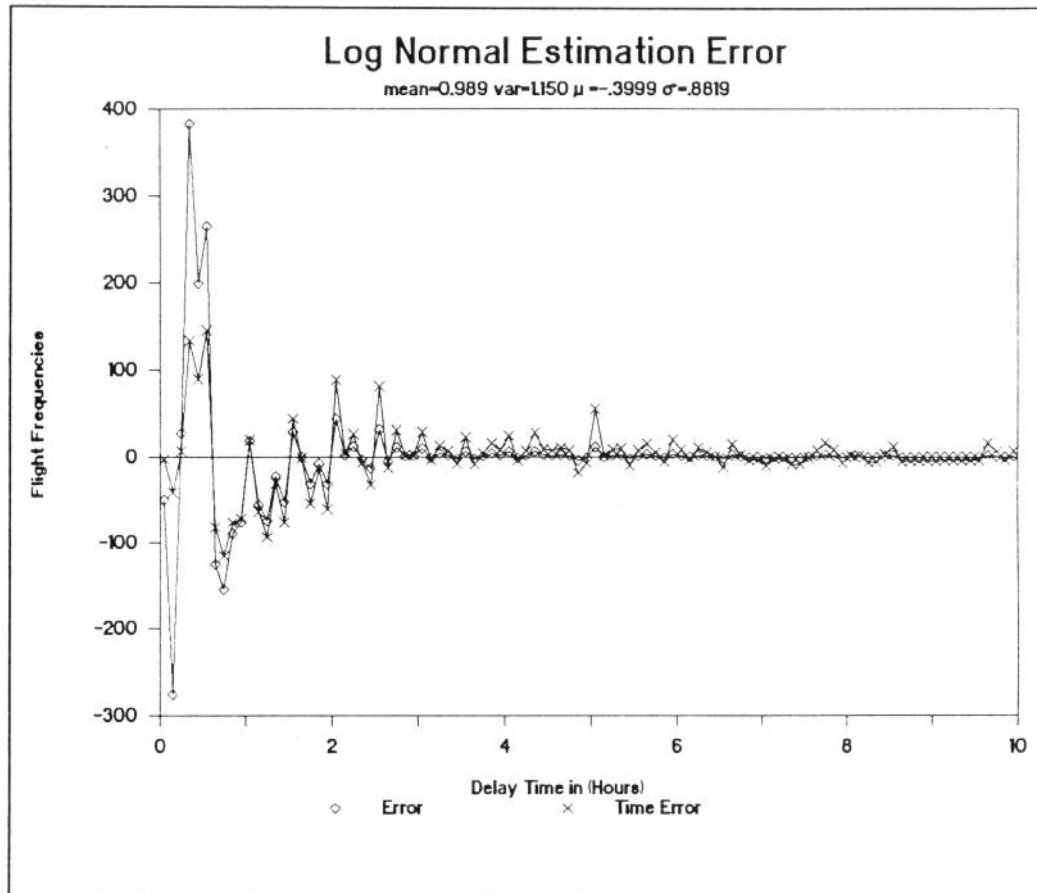


Figure 4-10 Delay time error

(b) Weibull Distribution Estimation:

Figure 4-11 shows the best estimated Weibull distribution for general delay with the following parameters $a1 = 0.75$, $a2 = 0.75$ and $a3 = 0.05$ as previously mentioned in the section 2.2 of this chapter.

The same graph is shown in **figure 4-12** but with five hours delay time duration.

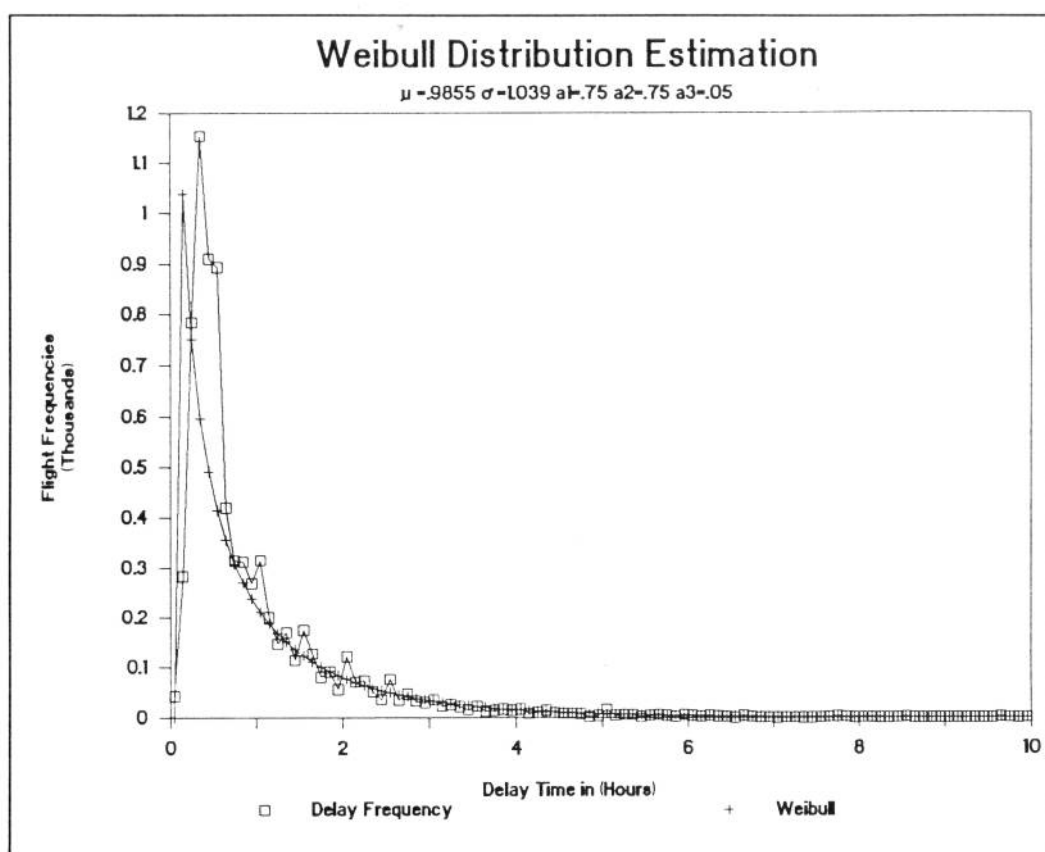


Figure 4-11 General delay and Weibull distributions

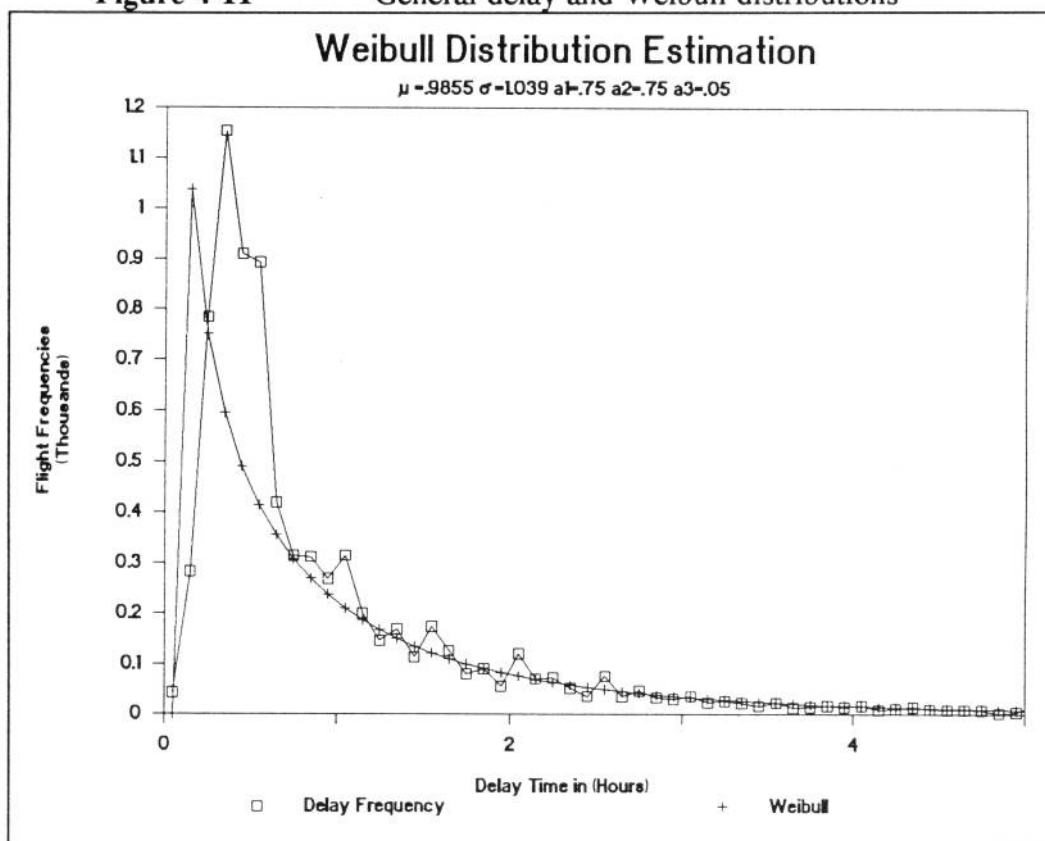


Figure 4-12 General delay and Weibull distributions

For delays within 45 minutes, a large error exists between delay frequency distribution and Weibull distribution as shown in **figure 4-13**. For 12 minutes delay time about -800 delays error exists and for 24-36 minutes delay time there is about +500 delays error from the actual general delay distribution function. The delay frequency error is less after one hour delay time which is about 100 delays error and then approaches zero value.

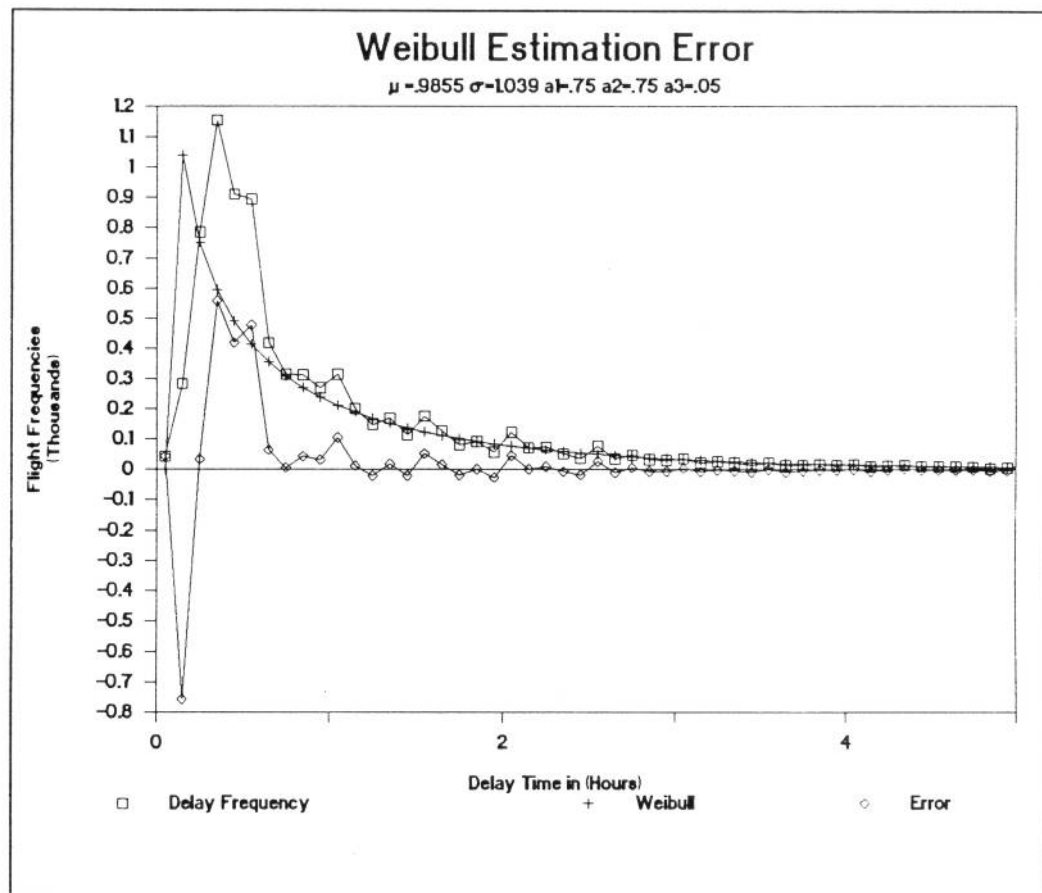


Figure 4-13 Estimation error

Figure 4-14 shows the delay error and the error percentage of the general delay distribution which appears to be around $\pm 100\%$ for one hour delay time duration delays.

The time error appears in **figure 4-15**, although 800 less delays for 12 minutes delay time only 100 delay hours error and about 200 hour delay time for about 500 delays error in the range of 24-36 minutes delay time duration.

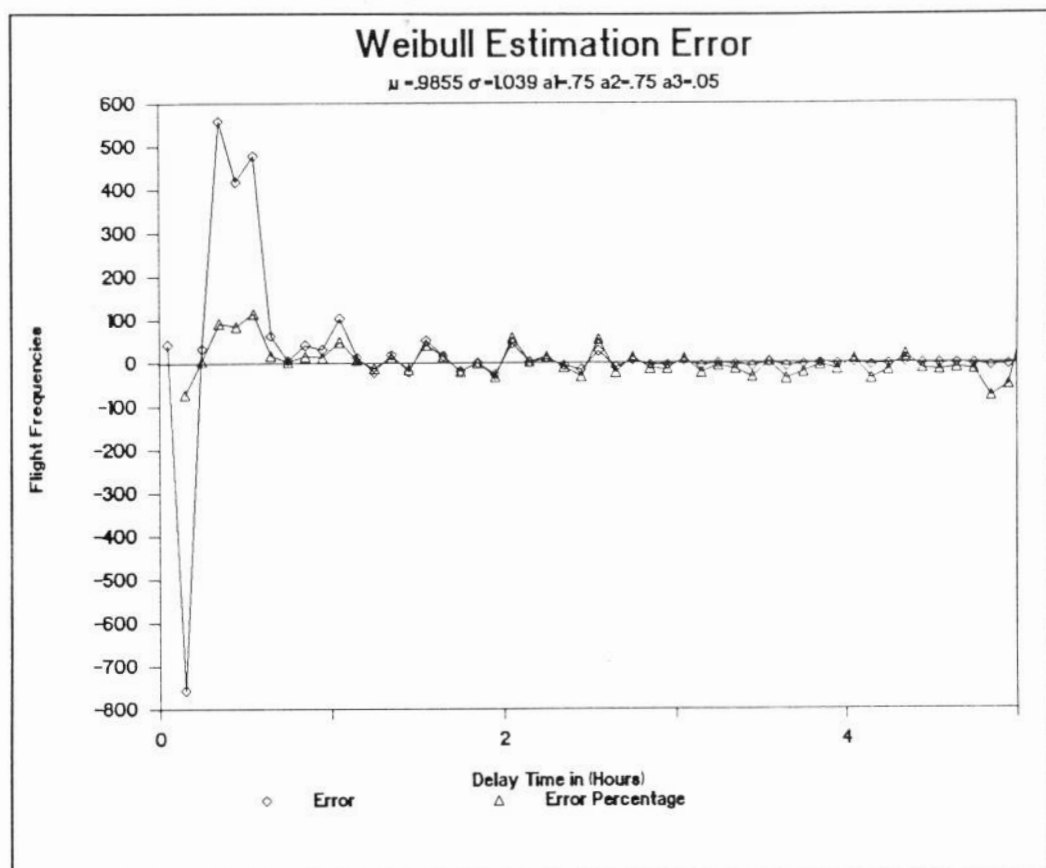


Figure 4-14 Delay error and the error percentage

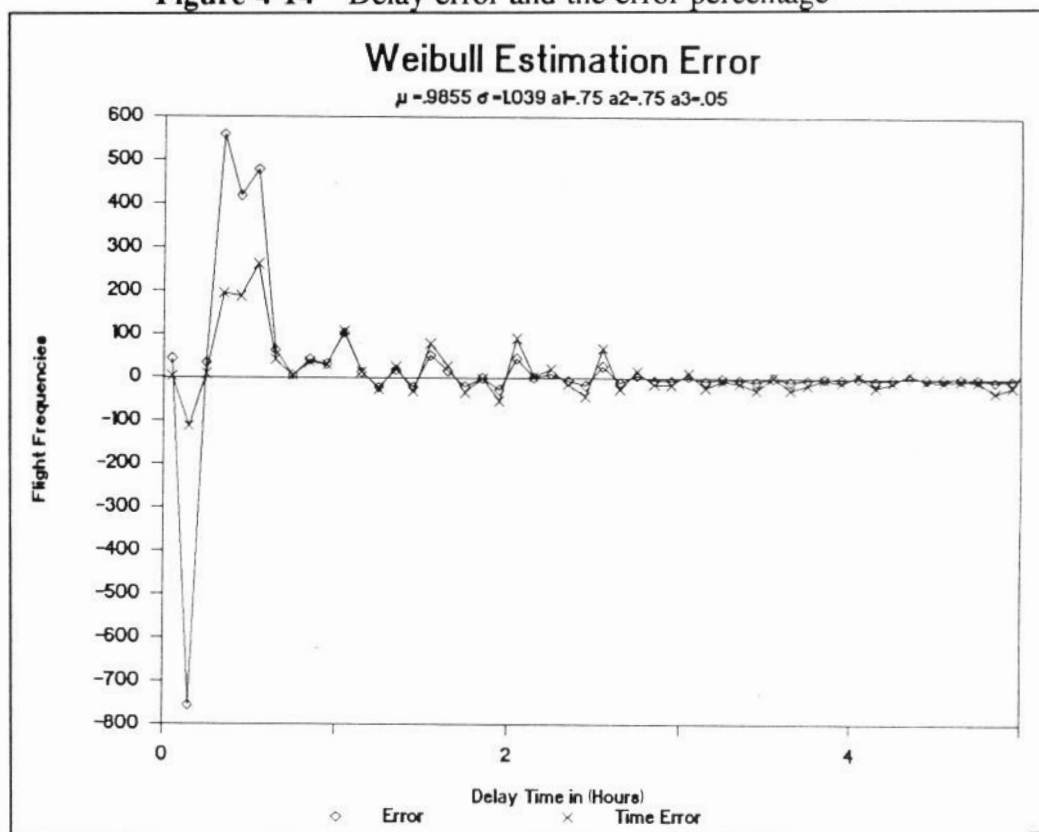


Figure 4-15 Time error

4.6 Original Delay Frequency Distribution Estimation:

This section illustrates the estimation of original delay distribution function including fitting into *lognormal* and *Weibull* frequency distribution functions. This includes demonstration of estimation accuracy i.e. frequency error, percentage error and time error.

(a) Lognormal Distribution Estimation:

Figure 4-16 shows the original delay frequency distribution with mean = 0.9926 and variance = 1.0708 and the lognormal distribution estimation with $\mu = -0.3752$ and $\sigma = 0.8577$.

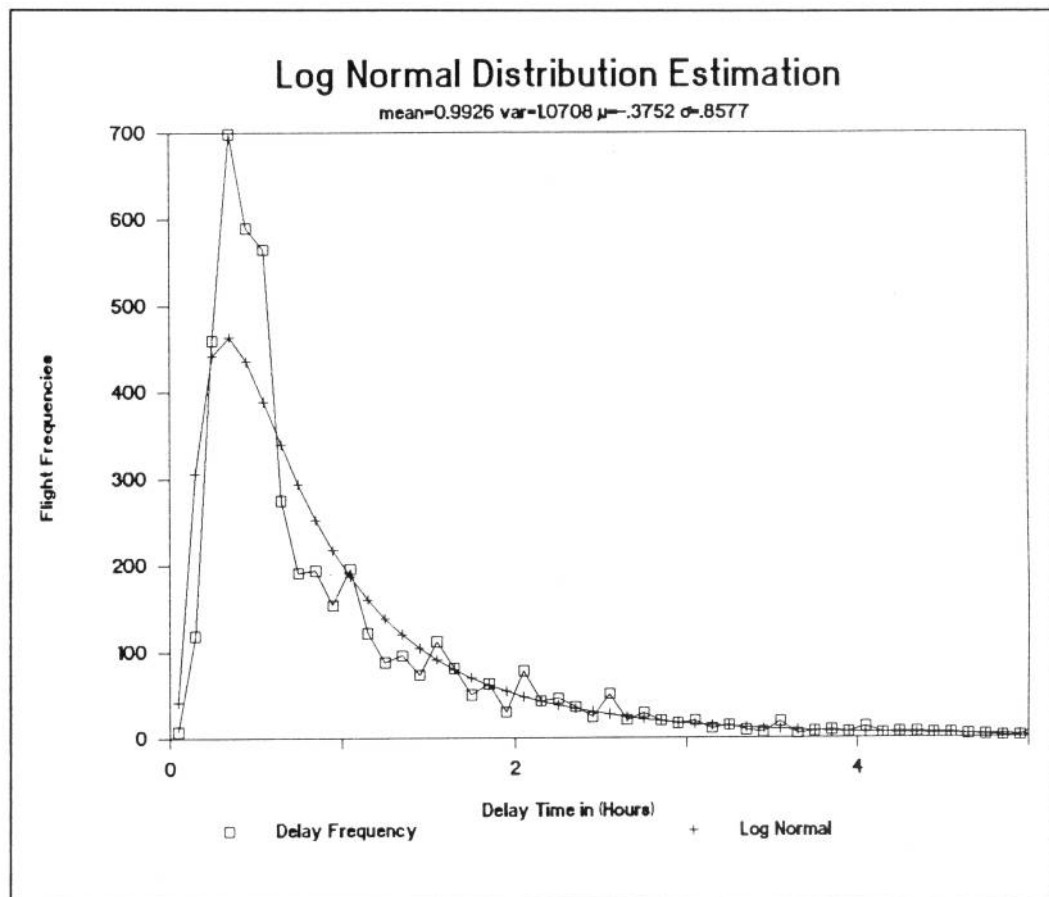


Figure 4-16

The error between both distributions appear in figure 4-17 for 12 minutes delay time duration about -200 delays error and more than 200 delays error between 24-36 minutes delay time. After one hour delay time the error approaches zero value.

Error percentage, as appears in figure 4-18, is less than 60% for less than one hour delay time and less than 25% after 2 hours delay time. Figure 4-19 shows the time error.

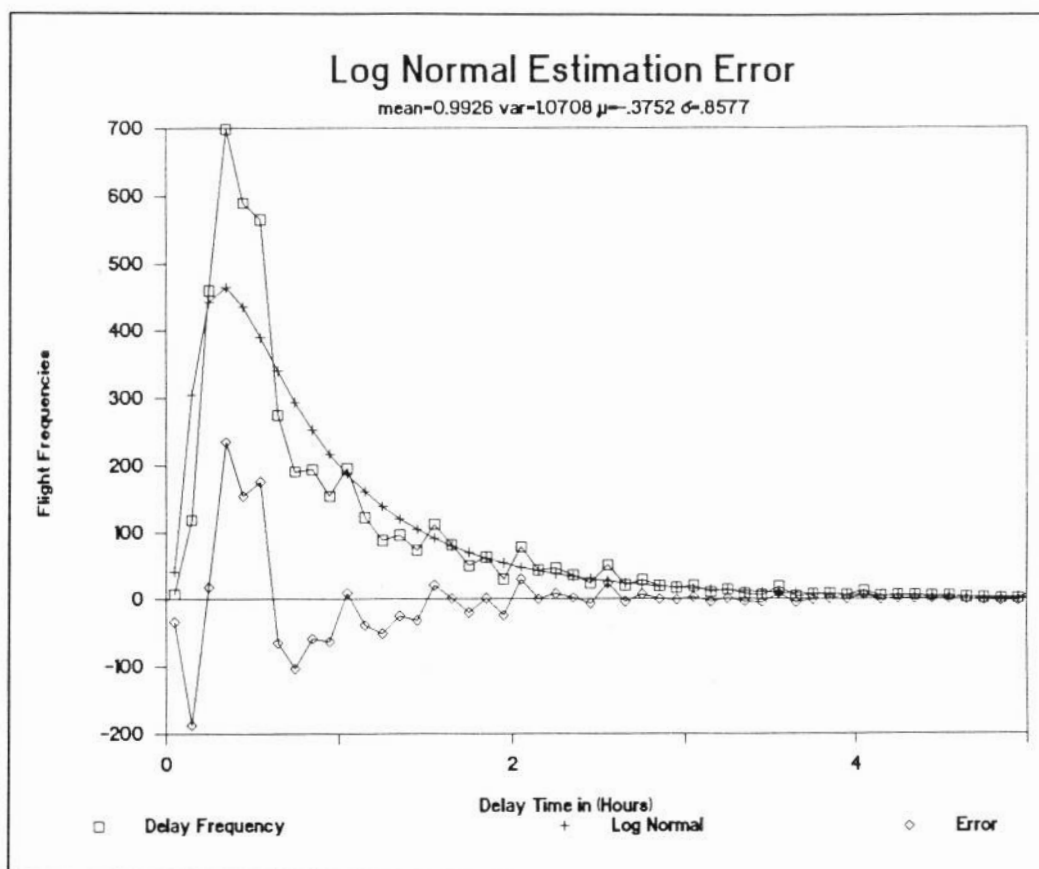


Figure 4-17

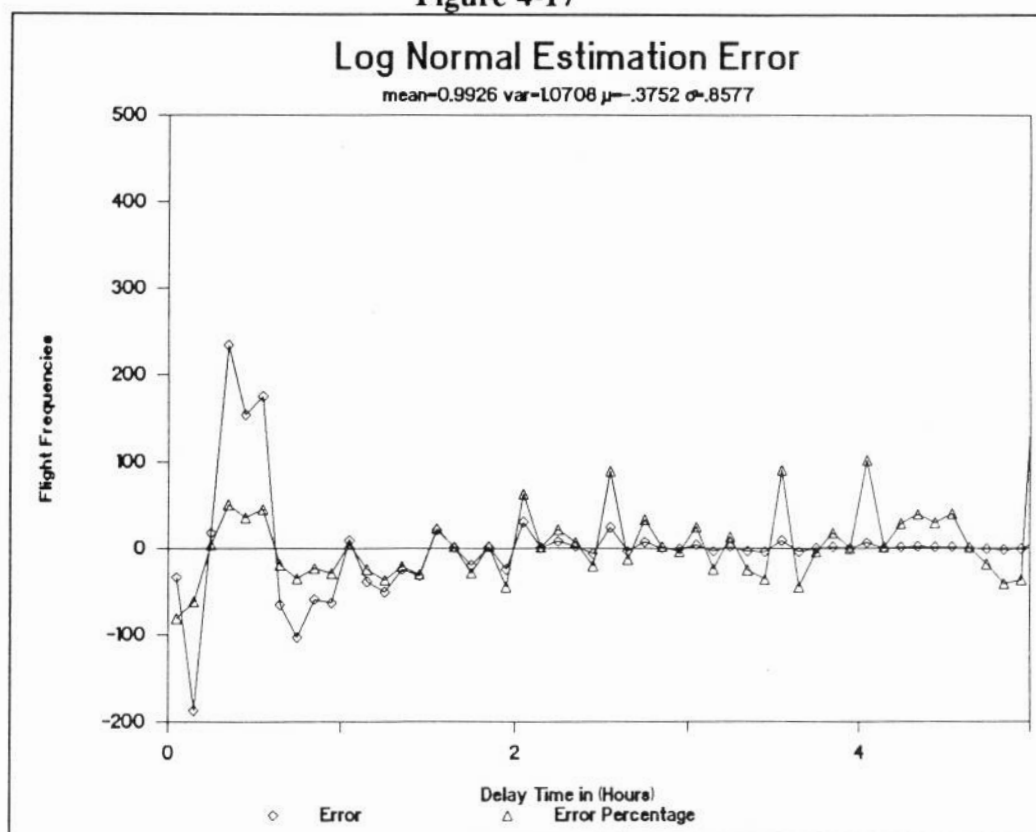


Figure 4-18

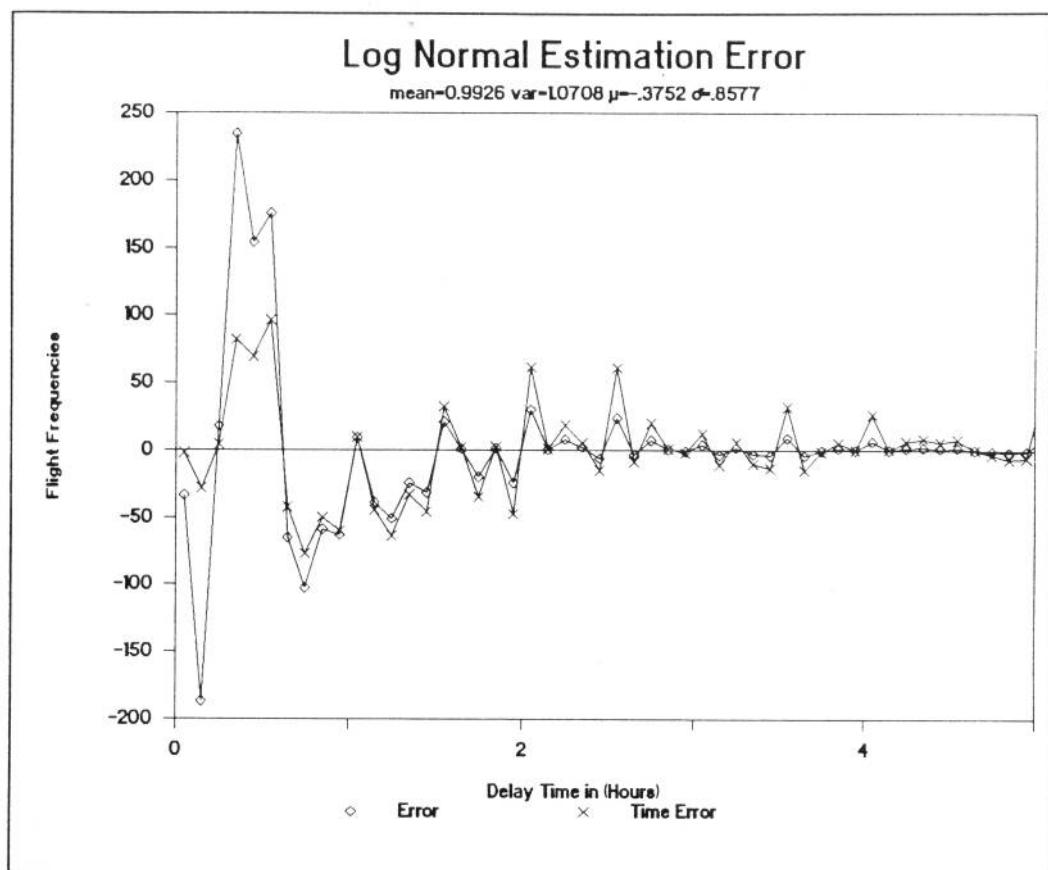


Figure 4-19

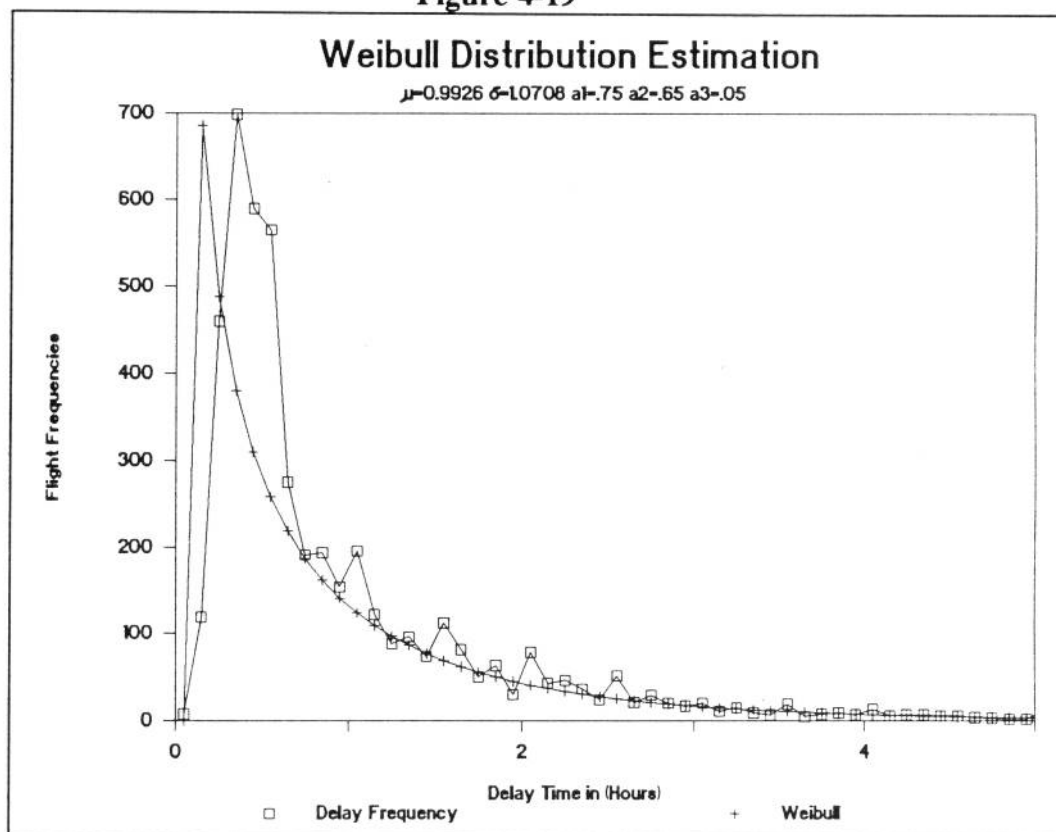
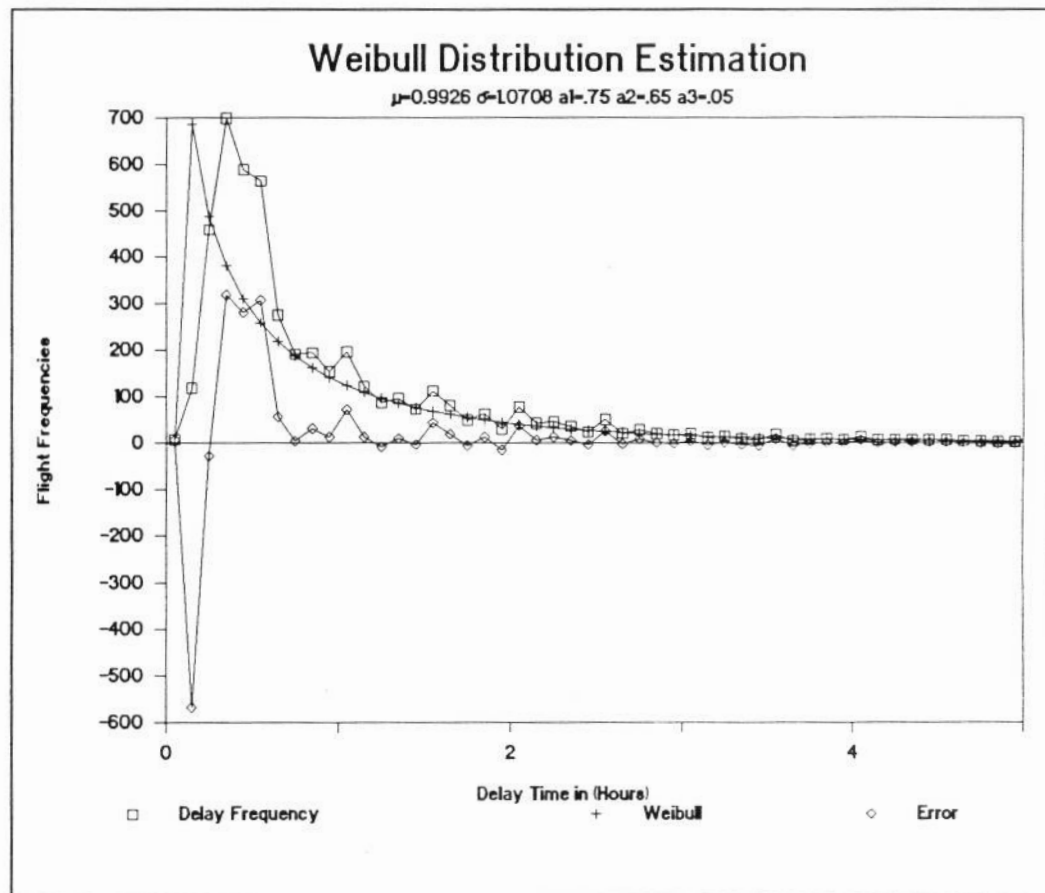


Figure 4-20

(b) Weibull Distribution Estimation:

Figure 4-20 shows the *original delay* frequency distribution and the Weibull distribution with estimated parameters $\mu = 0.9926$, $\sigma = 1.0706$, $a_1 = 0.75$, $a_2 = 0.65$ and $a_3 = 0.05$.

The error of original and Weibull distribution is shown in figure 4-21. For 12 minutes delay time about -600 delays exist and about 300 delays error for 24-36 delay time durations then error approaches zero.



The error percentage is about $\pm 100\%$ for one hour delay time as shown in figure 4-22. Error and time error appears in figure 4-23.

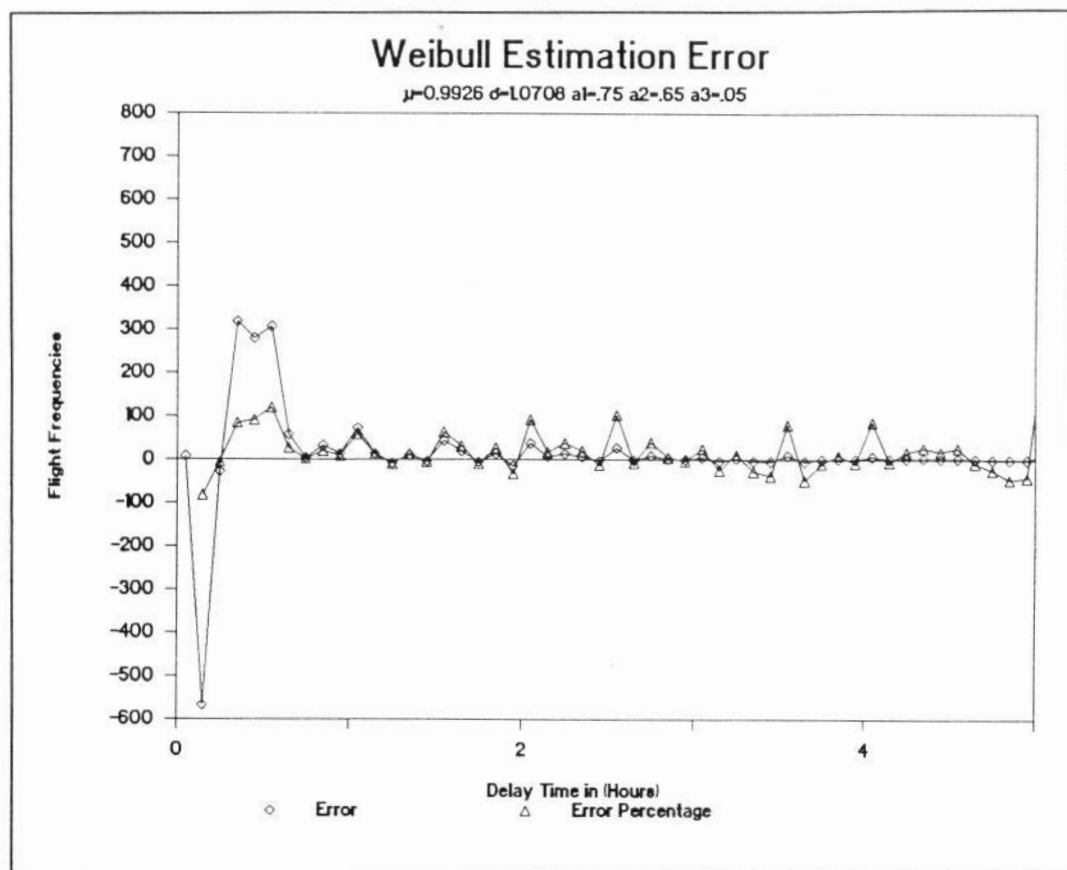


Figure 4-22

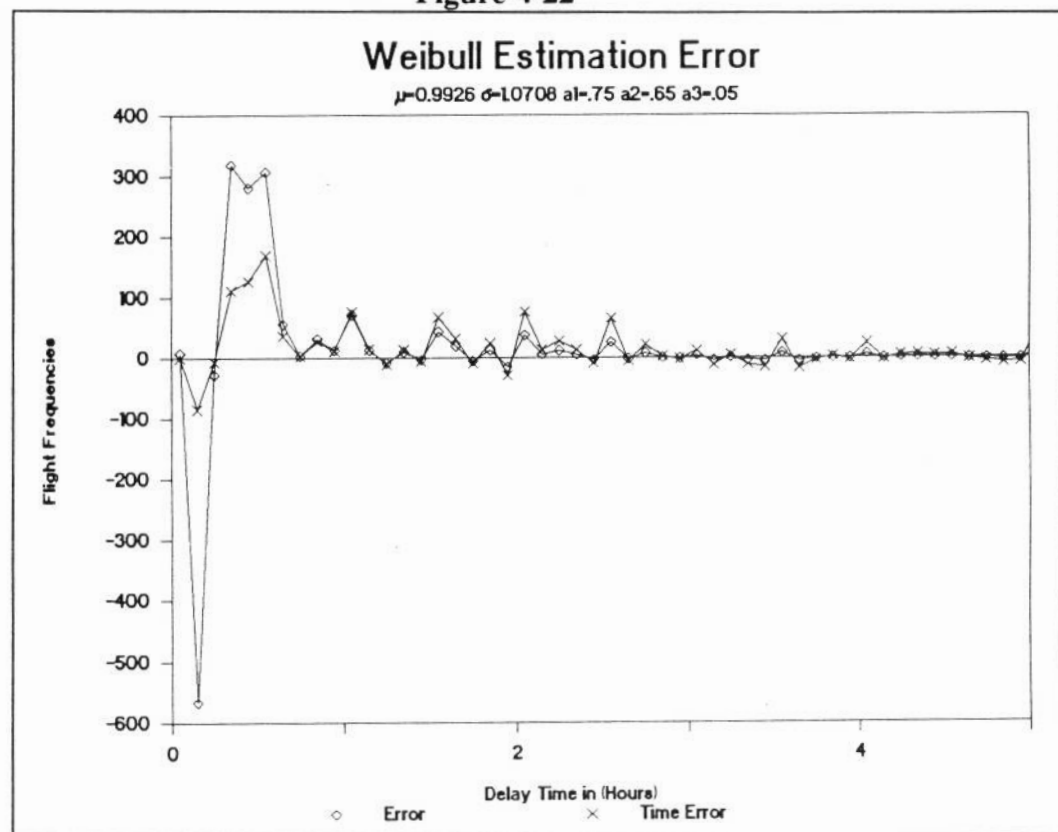


Figure 4-23

4.7 Reactionary Delay Distribution Estimation:

(a) Lognormal Distribution Estimation:

Figure 4-24 shows the *reactionary delay* frequency distribution with mean = 1.1609 and variance = 1.4038, and lognormal distribution estimation with $\mu = -0.2077$ and $\sigma = 0.8448$.

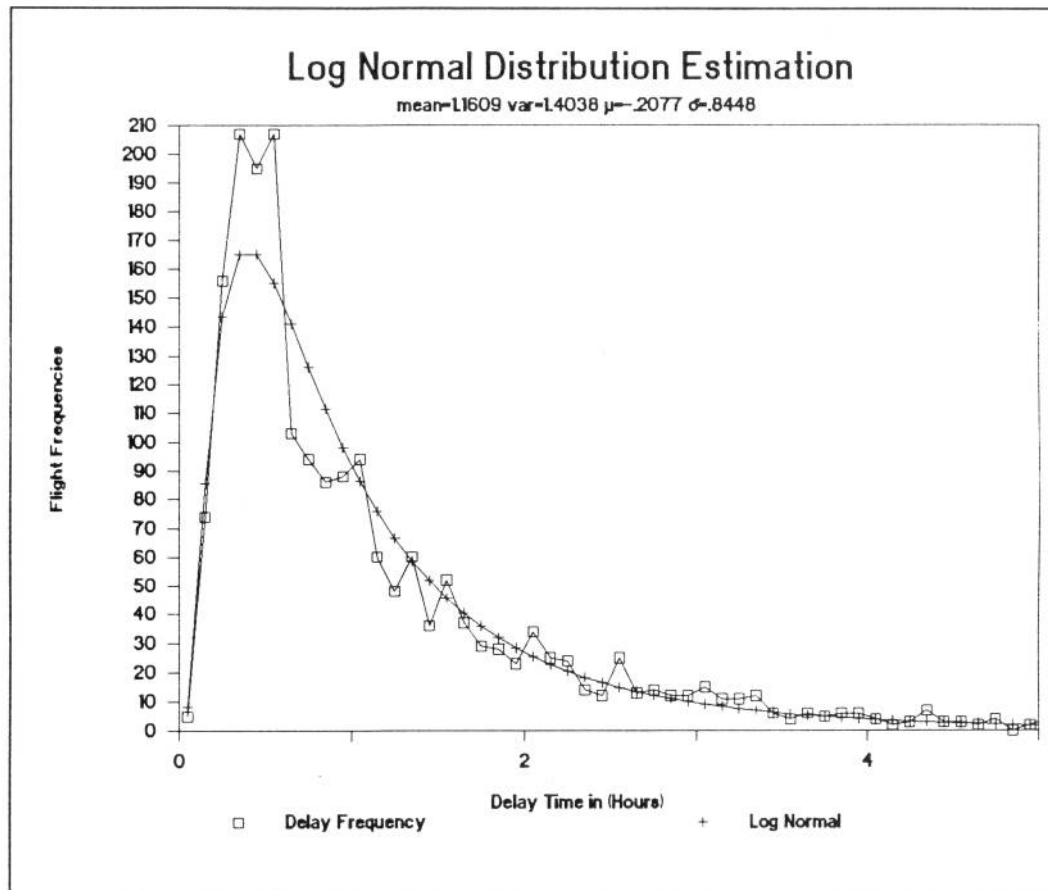


Figure 4-24

The error between actual reactionary delays and lognormal distribution appear in **figure 4-25** where at 24-36 minutes delay time duration there is about 40 delays error. At 40-54 minutes delay time a negative of 40 delays error exists then the error approaches zero.

The error percentage appears in **figure 4-26** for less than one hour delay time duration the error percentage is $\pm 35\%$. For delay times between 2 hours and 4 hours the error percentage is about $\pm 50\%$ and for a delay time more than four hours the error percentage is more than 100%.

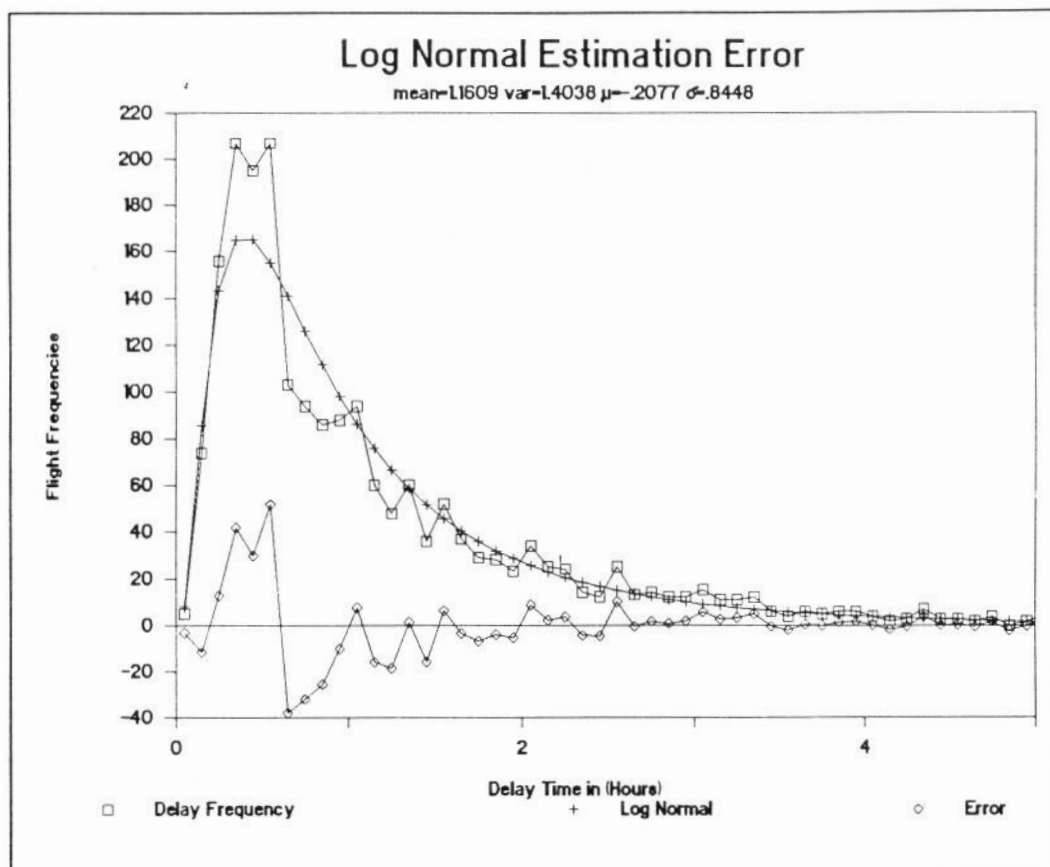


Figure 4-25

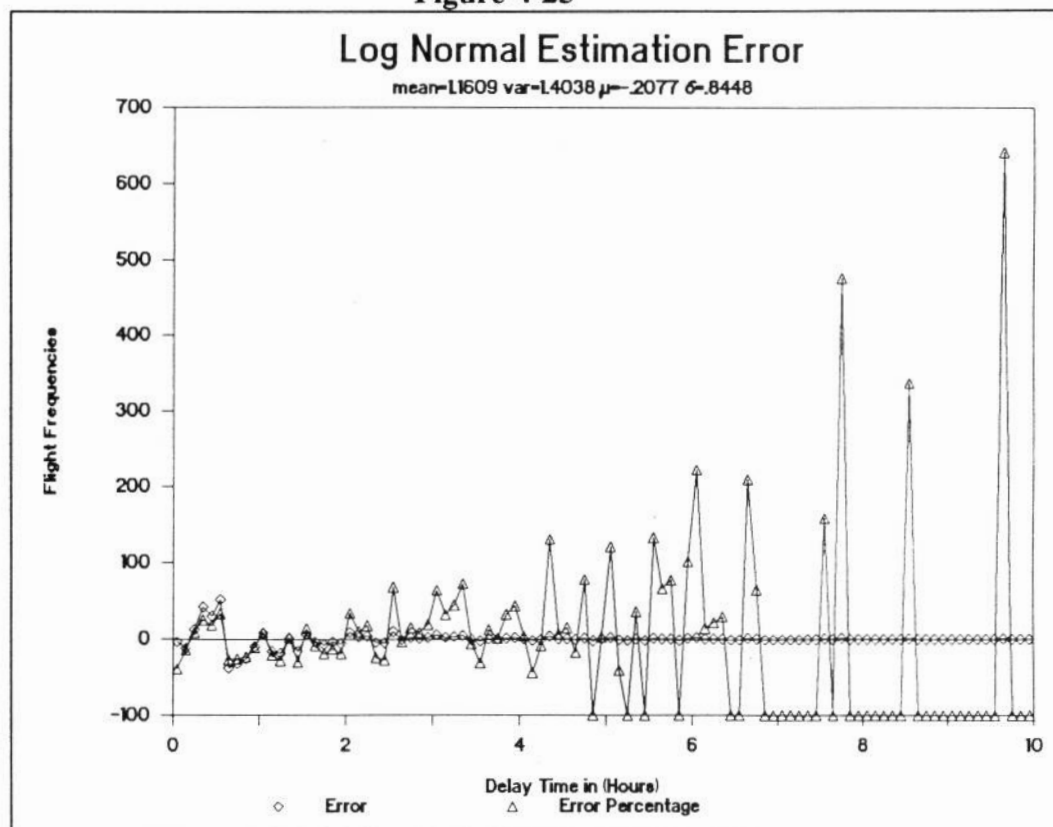


Figure 4-26

Error time appears in **figure 4-27** as ± 30 hours delays for less than one hour delay time duration and is ± 20 hours delays between 1-3 hours then it approaches zero value for more than 3 hours delay time.

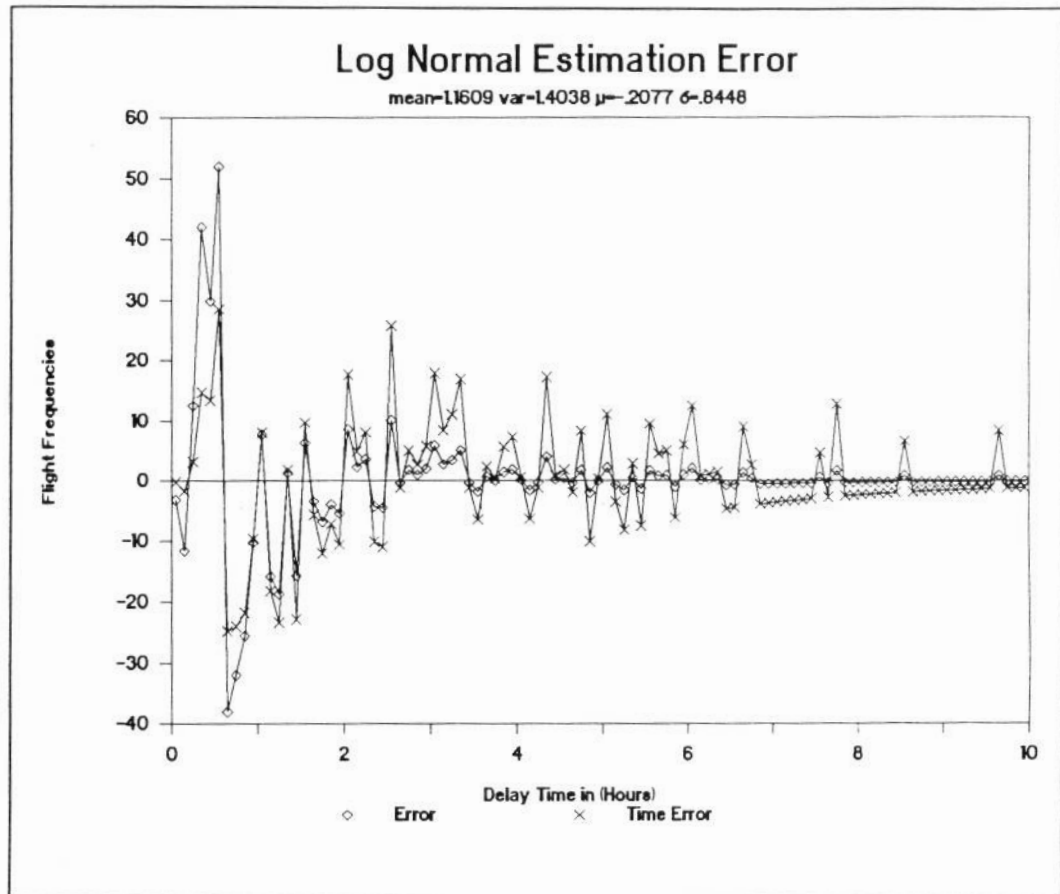


Figure 4-27

(b) **Weibull Distribution Estimation:**

Figure 2.28 shows the *reactionary delay* frequency distribution with $\mu = 1.1609$ and $\sigma = 1.4038$ and it shows also the Weibull distribution with estimated parameters, $a1 = 0.90$, $a2 = 1.05$ and $a3 = 0.05$.

The error between actual reactionary delay distribution and estimated Weibull distribution appears in **figure 4-29** where at 12 minutes delay time -120 error delays exist and between 24 minutes and 36 minutes delay time duration about 80 delays occur than it approaches zero for more than one hour delay time duration.

Error percentage is about $\pm 40\%$ between one hour to 4 hours delay time, about $\pm 100\%$ between 4 - 6 hours delay time and more than 100% for more than 6 hours delay time, as observed from **figure 4-30**. **Figure 4-31** shows the error time of actual reactionary and estimated Weibull distribution.

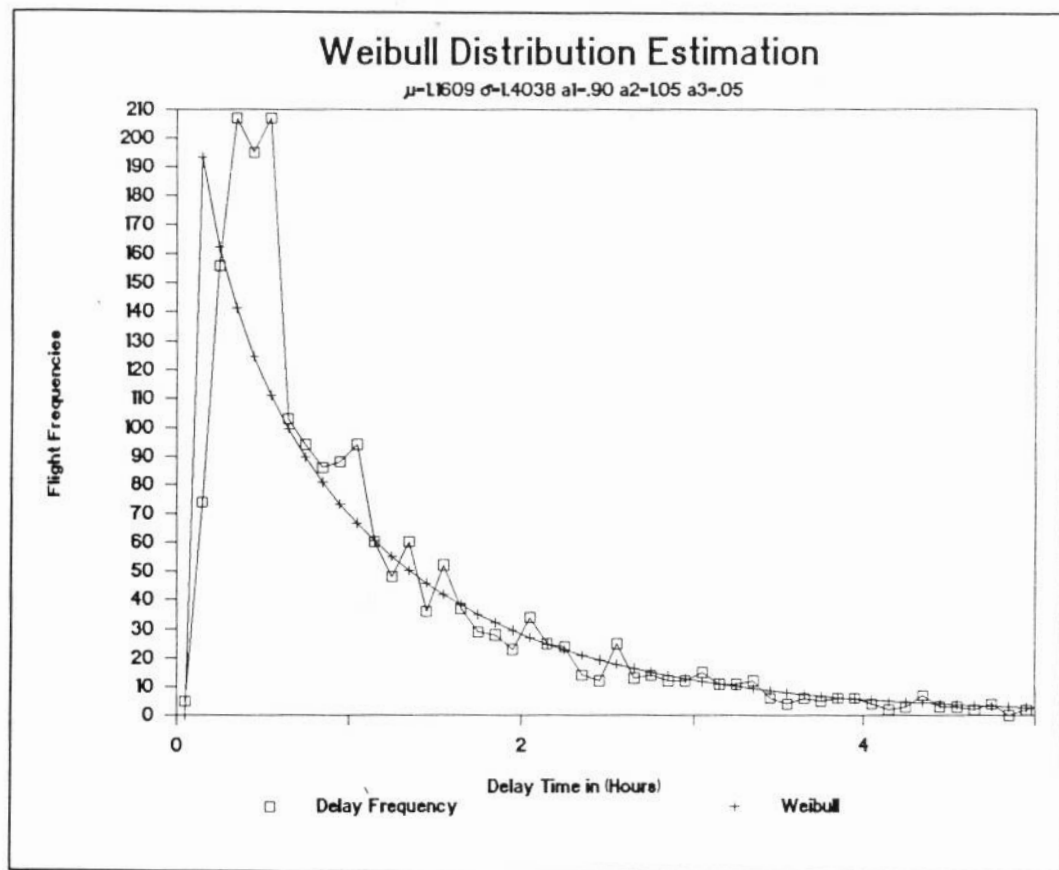


Figure 4-28

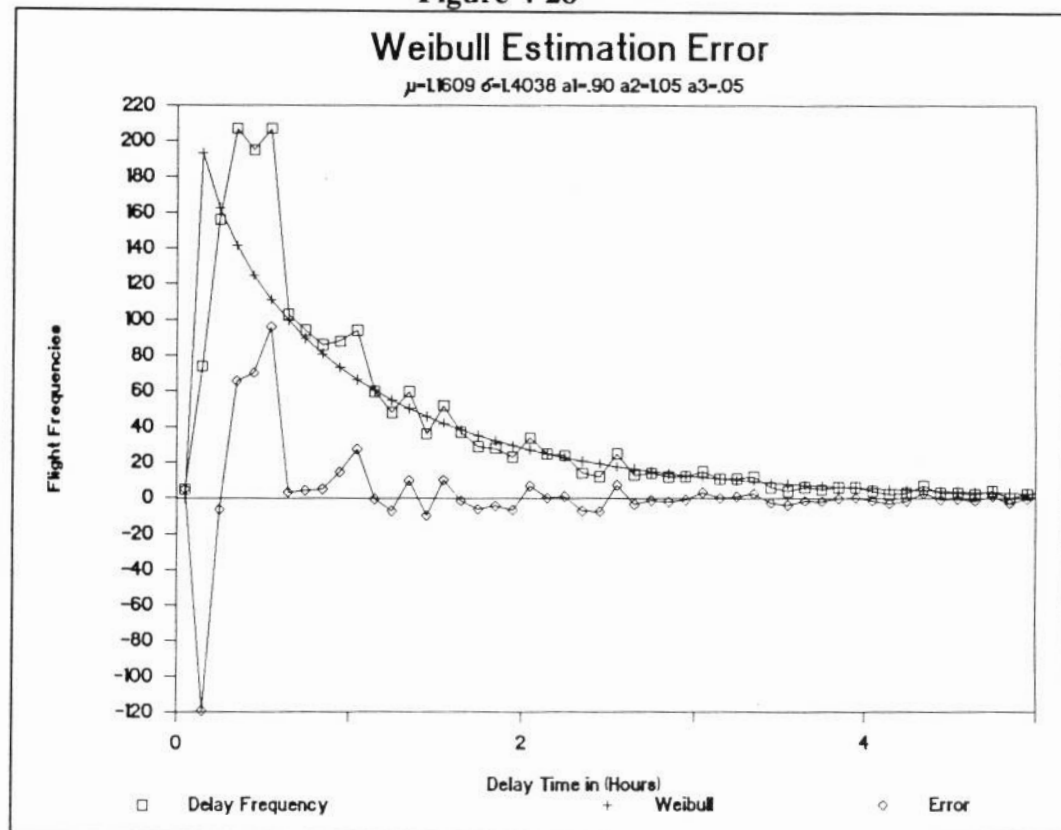


Figure 4-29

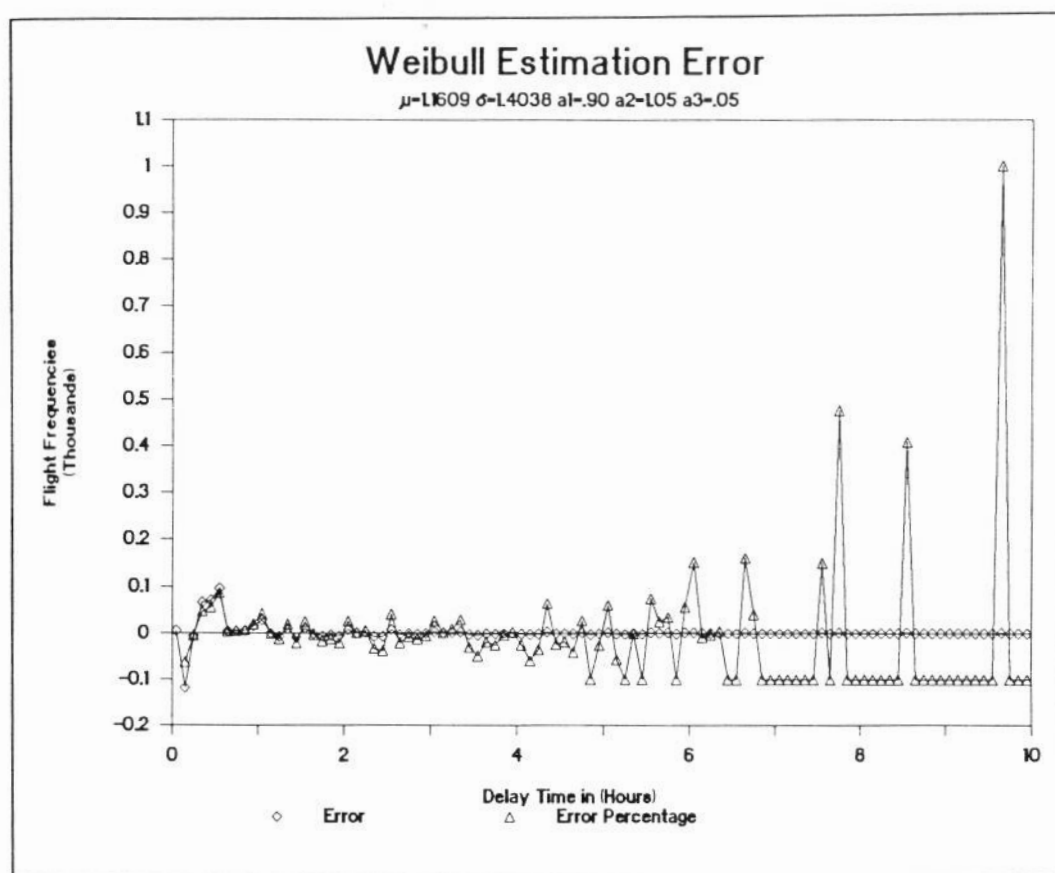


Figure 4-30

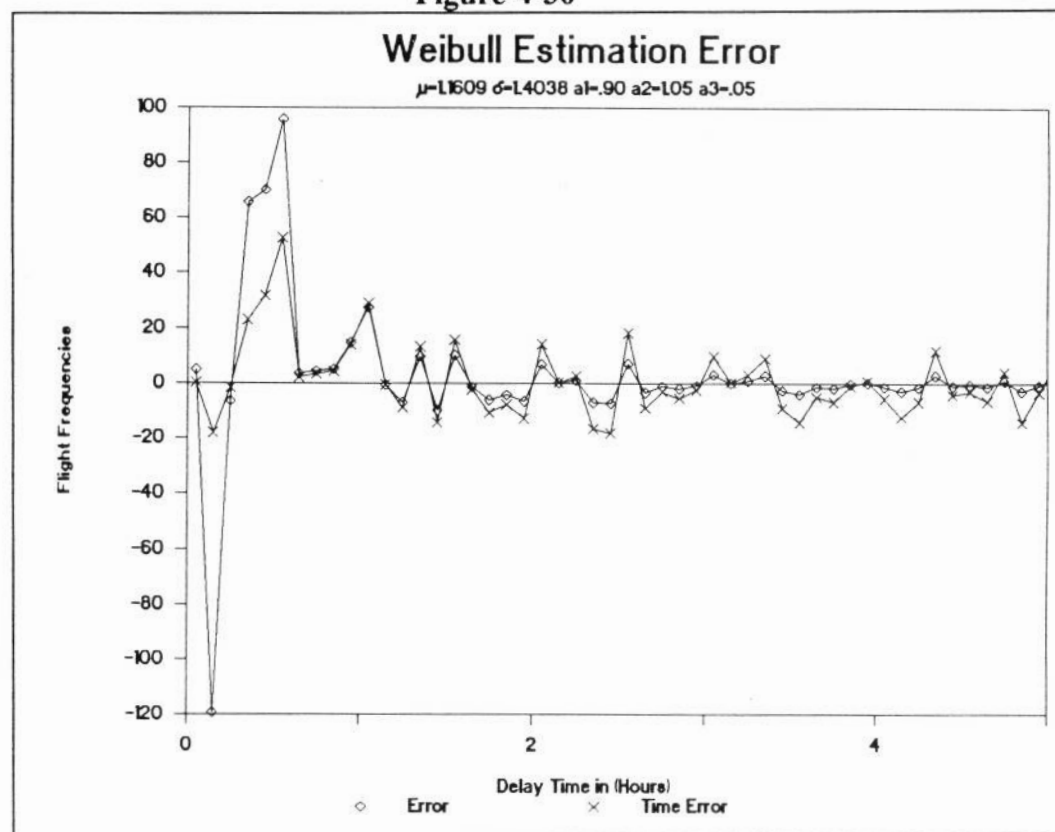


Figure 4-31

4.8 General Delay Distributions Comparison:

The section focuses on the comparative discussions on the general delay distribution function, lognormal estimation distribution and Weibull estimation distribution. **Figure 4-32** shows the three distribution functions.

As noted from the graph that both lognormal and Weibull estimation do not fit with the general delay distribution perfectly especially for the first half an hour. The Chi-squared test is applied to test the goodness of fit, it shows high values in both distributions but it shows Weibull distribution has a higher chi square value than lognormal. Chi square test for lognormal = 873 and Chi square test for Weibull = 2230.

The standard error for sample distribution is evaluated and shows similar results to chi square where standard error for lognormal estimation is 169 and for Weibull estimation is 172.

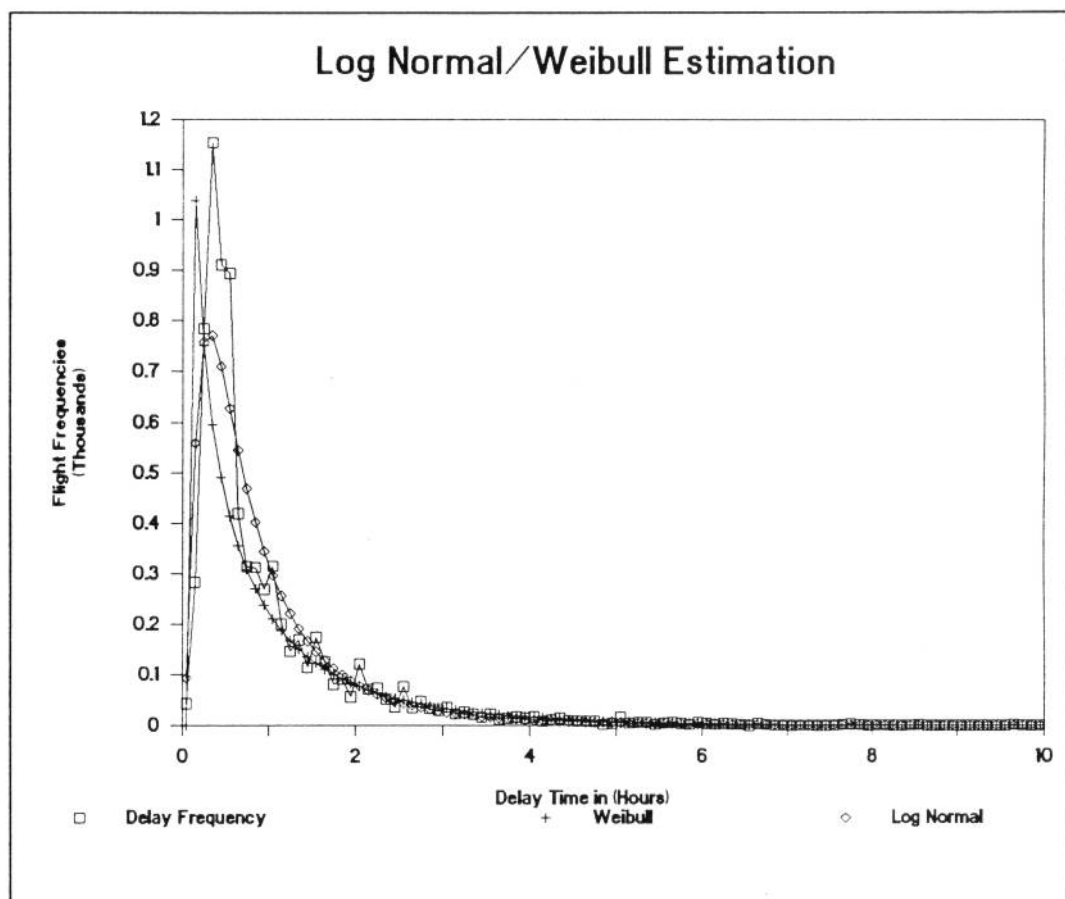


Figure 4-32

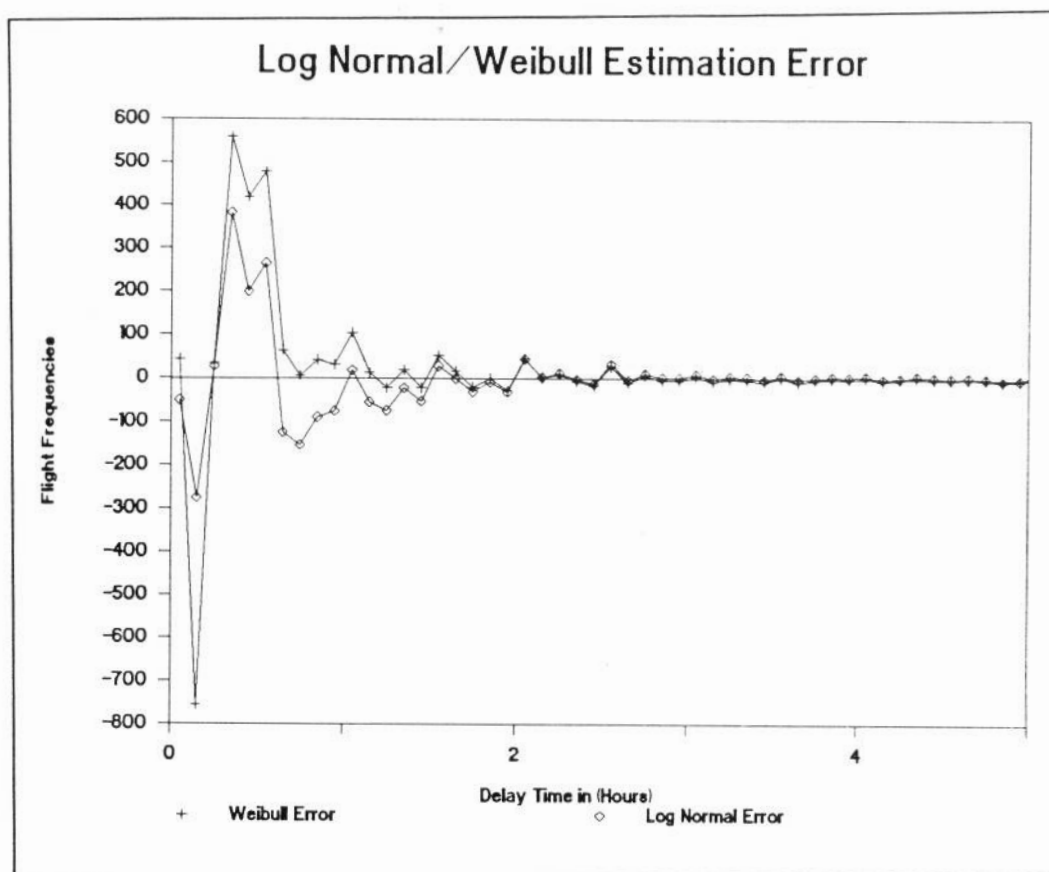


Figure 4-33

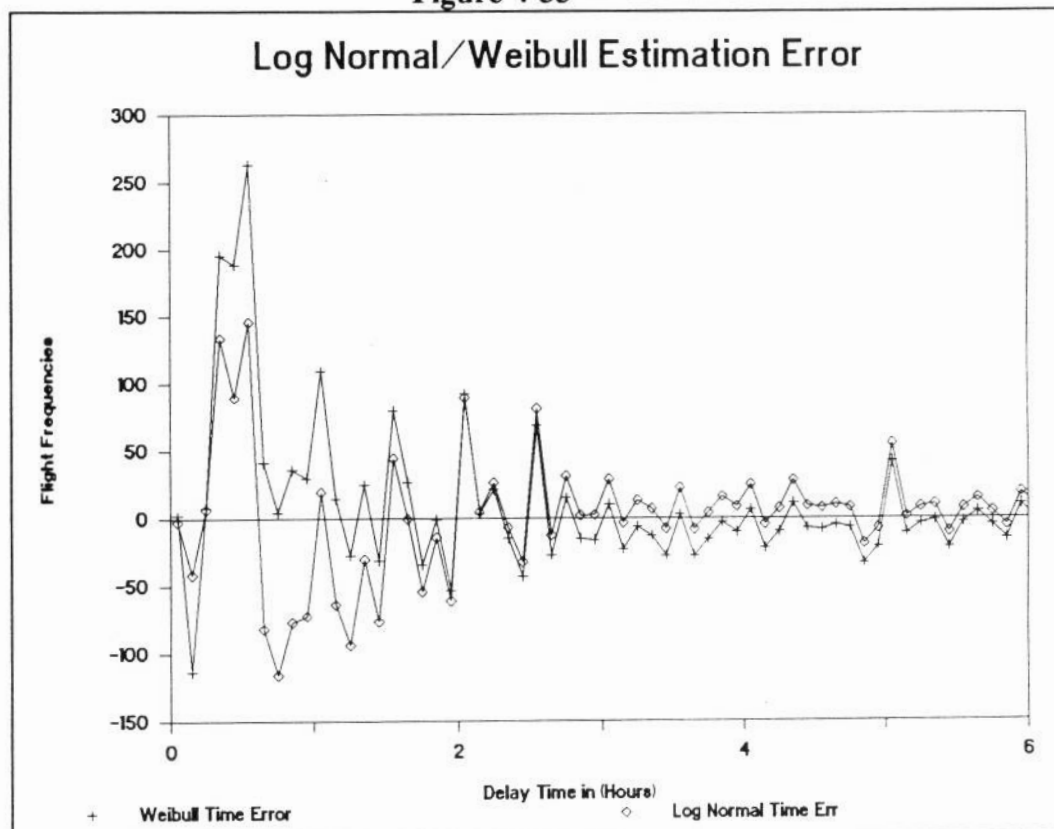


Figure 4-34

Figure 4-33 shows the frequency error of lognormal and Weibull distribution function with the general delay frequency distribution and **figure 4-34** shows the error in the delay time distribution function of the lognormal and Weibull with the general delay time distribution function.

4.9 Conclusion:

Lognormal estimation with mean = 0.989, variance = 1.150, $\mu = -0.3999$ and $\sigma = 0.8819$ fits the general delay distribution function better than Weibull distribution function with $\mu = 0.9855$, $\sigma = 1.039$, $a1 = 0.75$, $a2 = 0.75$ and $a3 = 0.05$. Similarly with original delay distribution estimation where lognormal shows better fit compared to Weibull.

For the purpose of utilizing this conclusion for schedule disturbance and punctuality simulation later in this research, the lognormal distribution estimation which has been represented by general, original and reactionary delays is the most acceptable distribution as compared to Weibull, in spite of the fact that lognormal estimation has a high percentage error for the first half of an hour delay time.

Empirical distribution is also a valid option in this case if a higher level of accuracy is needed. For the purpose of demonstration the schedule simulation in chapter (6) and chapter (7) the lognormal distribution will be used.

Chapter (5)

MEASUREMENT OF PASSENGERS ATTITUDE TOWARDS PUNCTUALITY

This chapter examines the passengers' attitude towards delays and the formation of the passengers *impact function* and their possible future reactions. This impact function is based on an analysis of the influence of factors such as passenger's trip purpose and different delay times. Based on results of passengers' reactions and impact function the *revenue loss function* is estimated.

A passenger interview survey is conducted to determine these relationships and others related to punctuality awareness and punctuality impact.

Section 5.1 gives a description of the overall objectives of this chapter and highlights the previous work in this area. Section 5.2 describes the *major areas* of the interview survey and justifications for its consideration i.e. punctuality awareness, delay impact, passenger future actions in case of delays and cancellations and airline compensations in case of delays occurrence. Section 5.3 illustrates the *process of questionnaire* design and handling. The final survey questionnaire is described in detail and the benefits of conducting a pilot survey are identified and adopted. Section 5.4 explains the *method of* conducting the survey, sample size including international and domestic flights. The same section also discusses the method of processing the survey responses and introduces the analysis approach and statistical package used for this purpose. Section 5.5 presents details *results and analysis* based on the responses by different categories i.e. vacationers and business travellers, domestic and international passengers. Section 5.6 summarizes the *survey findings* and determines the average revenue loss relevant for punctuality management.

5.1 INTRODUCTION:

The objectives of this chapter are to demonstrate the method of measuring the *passengers' impact* from delays and/or cancellations including business and leisure travellers, to estimate the *passenger revenue loss* expected due to occurrence of delays and cancellations, and to demonstrate the application of a passenger survey including design and analysis which will determine relationships to be used for management strategies.

Airlines may use an approach to determine the cost of delay from the airline perspective without considering the impact on passengers. Eastern Airlines made a study on delays and cancellations which was published in the AGIFORS

proceedings as a new approach to their despatch reliability and operational cost. It included a mathematical representation of the nature of the revenue loss and delay time relationship (ALBERT (59)).

Figure (5-1) illustrates ALBERT findings that the passenger revenue loss and delay time have the type of relationship in which there are three major parameters A, B and C are defined as follows:

- A = Maximum delay time duration which yields no impact on revenue.
- B = Delay time duration which yields maximum % passenger revenue loss.
- C = Maximum % passenger revenue loss due to impact of delays.

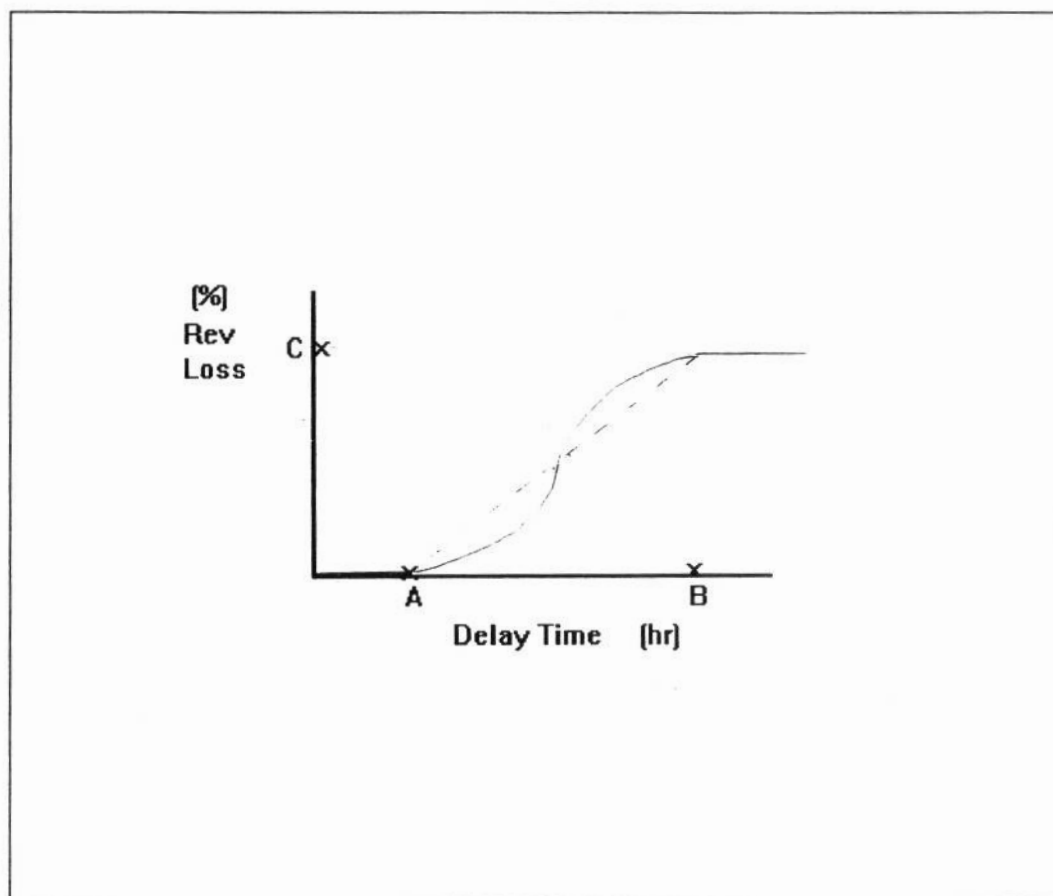


Figure (5-1) Passenger Revenue Loss Relationship

The expression of the passenger revenue loss function is an upward trend. It assumes that the revenue loss trend is a sinusoidal relationship. Mathematically two formulae were derived to be used to determine the loss revenue for a given delay time assuming values for A, B and C parameters defined earlier. This relationship could also be achieved by applying properly segmented portions of

a parabolic, hyperbolic, quadratic, tangent or exponential expression. The sinusoidal expression was selected because no segmenting is necessary (ALBERT (59)).

One of the major objectives for the survey is to estimate the A, B and C parameters and passenger revenue loss trend which is called here *revenue loss function*.

5.2 MAJOR SURVEY AREAS:

In the punctuality survey six areas are surveyed in which each area includes different variables. Some of these variables have a direct relationship to punctuality management and some have an indirect relationships. The following are the survey areas that are considered in this survey and explanations of the objectives and reasons behind surveying them.

5.2.1 Punctuality Awareness:

Awareness of punctuality is related here to the individual passenger and whether he/she is aware of airline operations and to what extent this is reflected in their trip plans. In other words if passengers are frequently experiencing delays, they will take account of such delay time and may incorporate a time buffer in the trip plans. This is regardless of how they feel about the delays and the overall punctuality.

This variable is surveyed indirectly by asking passengers the number of flights made by them and the number of flights delayed for more than half an hour for the last 12 months. The second variable is to determine the passenger's current satisfaction level on punctuality. This question supports the previous question. For the latter variable the question has to be on a specific airline because different airlines have different punctuality reputation. In this case the question referred to Saudia because the survey is conducted in Saudia terminal. Both variables in this category concern passengers' views on historical experience.

5.2.2 Impact of Delays:

The objective is to determine a level of passenger impact if his/her flight is delayed. To determine global and more precise impact, five different delay times are considered in this survey i.e. delay of 0.5 hour, 1 hour, 2 hours, 4 hours and 6 hours. The level of impact is measured using the following scale in which passenger will respond using it. It ranges from very slight impact, slight impact, some impact, serious impact to very serious impact.

Then the impact of delays is analyzed for all the surveyed passengers in order that a function of passengers' impact with delay time can be developed. This function is called *delay impact function*.

5.2.3 Passengers actions in case of delays:

This variable shows the possible actions that passengers can take in case of the flight being delayed for a time which has a very serious impact.

As seen in section 5.2.2 that delay impact can be one of five. In this area of the survey it is required to identify the percentage of the passengers who are seriously impacted and what is their future actions. The objective is to estimate the average passengers *revenue loss* occurring due to loss of passengers.

Three possible actions are highlighted to passengers in this survey. Either passenger will *stay waiting* for the flight until it is ready or will *come* for the next available flight or *cancel* this flight and find alternative means of transport such as car/bus if the distance is short or other airlines if distance is far.

Then all passengers who take 'cancel this flight and find alternative' action are considered as a part of revenue loss. The rest of the passengers are considered as a portion of retained revenue but are seriously impacted.

5.2.4 Compensation in case of delays:

Most of the passengers understand that airlines have punctuality problems especially if those are due to technical and safety reasons but on the other side they require special treatment and arrangements in case of occurrences of such delays. This survey area explores the dimensions of possible compensation that airlines can offer to reduce the delay impact on passengers. The following are types of compensation that airline can offer:

An airline can provide *catering services* including food and beverages to passengers while waiting in the departure lounge. Food can be in the form of a full meal or a snack depending on the delay time period and the airline's budget.

An airline can provide a *communication means* for business, vacationers and families i.e. telephone services. So in the case of serious delay passengers can easily make telephone calls to incorporate the flight delay

in his/her travel plan. There are also other means of communication which can be considered and will be vital to business travellers such as fax and telex facilities.

An airline can provide *financial compensation* to passengers who are subjected to loss because of delay occurrences. This compensation can be in the form of cash or refund of ticket coupon value or percentage of coupon value.

Although, all items of compensation will increase the cost of airline operation, it will also gain passengers satisfaction which helps to maintain or improve the operating revenue.

5.2.5 Future Influence:

This variable illustrates the influence of delays in the process of airline choice for future flights in which it will affect the airline's future revenue. Three levels of influence are expected, either no influence, some influence or great influence.

5.2.6 Passengers action in case of cancellation:

This variable shows the type of actions which can be taken by passengers in case of a flight cancellation:

Similar to section 5.2.3 that there are three actions that can be taken in case of cancellations; either *come* for the next available flight or *find* other alternative means of transports i.e. car/bus/other airlines or *cancel* the trip.

The objective of this question is to estimate the expected passenger revenue loss. So passengers taking actions 'find other alternative' and 'cancel the trip' are considered as a portion of the expected *loss in revenue*.

5.3 QUESTIONNAIRE DESIGN:

Questionnaire design is the major part of the survey in which many steps are involved up to the arrival of the final form of the questionnaire. This includes the objective (s) behind any question and the way of presenting the question.

A *pilot survey* was developed which contributed to the final design of a questionnaire and the approach of conducting the survey.

5.3.1 Pilot Survey:

In this survey, a pilot survey was conducted on selected international flights. Eight different international markets were surveyed with a *sample size* of 58 passengers. The survey was performed by interviewing passengers in the departure lounge after completion of immigration and custom checks. The interview takes an average of 10 minutes; 23 variables were surveyed. As expected the interview survey takes a considerable time to perform. In this case it took two weeks during the evenings.

A Statistical Analysis System (SAS) is a mainframe computer package that is used here to develop the statistical analysis. The analysis describes the major relationship between delay time and the impact on passengers and passengers actions in case of delay occurrence.

There are some improvements incorporated when developing the final survey as a result of the pilot survey and after a full statistical analysis of the results.

It is clear that the *stage length* of any flight has an effect on the passenger impact and consequently on revenue loss i.e. if the flight sector is short then delays with short time have more impact on passengers rather than long distance flights. In addition the possibility of losing this revenue is higher because passengers might use other means of transport available. So one of the pilot survey recommendation is to conduct the final survey in domestic sectors which most of the flights are *short sectors and more frequent operation*. A second major contribution the pilot survey determines is the influence of delays on *future airline selection* process because many passengers were stating that for that specific flight they will use Saudia but in future they will choose other airlines. A third contribution is the *valuation of delays* and how much passengers evaluate the loss occurred due to delays.

All these remarks are considered when designing the final questionnaire form.

5.3.2 Questionnaire Form Description:

The questionnaire form of passenger attitude towards punctuality survey has four major areas including background information on flight and passenger's experience, delay impact and action in case of delays, cancellation and personal information.

(a) **Background Information:**

Six variables are surveyed; three of them concerning flight information of the passenger and three concerning passengers' experience in punctuality and level of satisfaction.

Flight information:

- . Flight Number
- . Class of travel
- . Passenger's destination.

Passenger's Experience & Satisfaction:

- . Number of flights made during last 12 months.
- . Number of flights delayed for more than half hour in the same period.
- . Level of passenger's satisfaction with the current Saudia punctuality.

(b) **Delays:**

This area of the survey involves the most important variables used in revenue loss evaluation. It surveys four issues; first on impact of different delay times, second passenger's action in case of delay time with serious impact, third suitable compensation in case of delays, and fourth the future influence of airline choice.

(1) **Impact of Delays:**

Six different delay times estimate the overall behavior of impact function. Five levels of impact are explored in this questionnaire for each delay time:

- No impact
- Very slight impact
- Slight impact
- Serious impact
- Very serious impact

(2) Passenger action in case of delays:

Four different possible actions are included in this question which might be considered by passengers:

- Stay waiting until flight is ready
- Come for the next available flight
- Cancel this flight and find alternative, i.e. car/bus/train/other airlines.
- Cancel this trip

(3) Suitable Compensation in case of delays:

Five elements of compensation are considered to be suitable. These elements are classified as either extra services and/or facilities and/or money compensation. Some of these elements are low cost i.e. beverages/snacks or telephone services but it will reduce the delay impact for both vacationers and business travellers. The following are the compensations that are considered in the survey:

- Provide beverage services and snack for short delays and food for longer delays.
- Provide means of communications; telephone services for all travellers, telex/fax facilities for business and VIP travellers.
- Family and mother care facilities.
- Financial compensation
- Others if not mentioned.

Facilities for communications (telephone, fax, telex) are provided by airline. It can be proposed that airline provide them and passengers pay for its usage. This of course depends on the airline policy and capabilities.

(4) Future influence on airline choice:

This question estimates the level of influence of delays on airline selection decision in future.

(c) **Cancellation:**

The third area which is surveyed: the passenger's action is determined in case of flight cancellation. Three actions are highlighted for passenger's consideration:

- Come for the next available flight.
- Find alternative means of transport.
- Cancel the trip.

(d) **Personal Information:**

Three variables are considered in this area for the purpose of analysis and cross tabulations needed in the statistical analysis of the survey.

- Nationality of passengers.
- Purpose of passenger's trip (Business / vacationers / others).
- Monthly income group.

5.3 Survey Questionnaire Form:

Considering the descriptions and findings from pilot survey the final questionnaire form is designed as attached. Arabic and English languages are used in the form as needed.

Passenger Attitude Survey
Towards Punctuality

استفتاء الركاب حول دقة
المواعيد .

Hello, we are conducting a survey regarding schedule punctuality. I hope you allow me taking 3-5 minutes of your time discussing your opinion towards punctuality.

مرحباً . نحن في صدد عمل استفتاء للركاب حول دقة المواعيد وبمدى تأثيرها على الركاب . أرجوا ان تسمح لى ٣-٥ دقائق من وقتك لمعرفة آرائك .

BACKGROUND

1. Flight Number ١- رقم الرحلة .
2. Class ٢- درجة السفر .
3. Destination ٣- المحطة الأخيرة .
4. How many flights have you made in the last 12 months? ٤- كم عدد الرحلات التي قمت بها خلال الاثنى عشر شهر الماضي ؟
5. How many flights you remember were involved a delay more than 30 minutes? ٥- كم عدد الرحلات التي تذكر انها تأخرت أكثر من نصف ساعة ؟
6. Are you satisfied with current Saudia punctuality? ٦- ما هو مستوى رضاك بالسيب لدقة مواعيد رحلات السعودي ؟

غير راضى
Not Sat.
1.

راضى
Satisfied
2.

راضى جداً
Highly Sat
3.

DELAYS

7. What is the impact on you if this flight is delayed for the following times?

٧- ماهو مدى التأثير عليك اذا تأخرت هذه الرحلة للأوقات التالية ؟

اوقات التأخير	لا تأثير	تأثير بسيط جداً	تأثير بسيط	تأثير قوى	تأثير قوى جداً
Delay Time	No Impact (1)	V.Slight Impact (2)	Slight Impact (3)	Serious Impact (4)	V.Serious Impact (5)
Half Hour					
One Hour					
Two Hours					
Four Hours					
Six Hours					

8. What is your possible action if this flight is delayed for _____ Hrs?
[Delay Time in Q. 7 scale (5)]

٨- ماهو رد فعلك المتوقع في حالة تأخير هذه الرحلة _____ ساعة ؟ (حسب سؤال رقم ٧)

- a. Stay waiting until ready. ☐
- b. Come for next flight. ☐
- c. Cancel this flight and find alternative. ☐
- d. Cencel this trip. ☐

أ- انتظر الرحلة حتى تجهز

ب- افسر للرحلة القادمه

ج- انسى هذه الرحلة و اوجد البديل

د- انسى السفر

9. What is the suitable compensation if this flight is delayed for two hours?

٩- ما هو التعويض المناسب لك اذا تأخرت رحلتك لمدة ساعتين ؟

- a. Provide food/beverage services. ☐
- b. Provide telephone services. ☐
- c. Family/mothercare facilities. ☐
- d. Financial compensation. ☐

أ- تقديم الطعام والمربطات

ب- توفير الخدمات الهاتفية

ج- تقديم تسهيلات للعائلات

د- تعويض مالى

SR

سعودى ريال

- e. Others. ☐

هـ - تعويضات اخرى

10. How much a delay of two hours will influence your airline choice in future?

١٠ - ما مدى تأثير تأخير الرحلة في اختيارك لشركة الطيران في المستقبل ؟

No
Influence

لا تأثير

Some
Influence

بعض التأثير

Great
Influence

تأثير قوى

CANCELLATION

11. What is your possible action if this flight is cancelled? ١١ - ما هو رد فعلك في حالة الغاء هذه الرحلة ؟

a. Come for next available flight.

أ - احضر الرحلة التالية

b. Find other alternative QAL/Car.

ب - اوجد البديل

c. Cancel this trip.

ج - الغى السفر

PERSONAL INFORMATION

12. Nationality :

١٢ - الجنسية

13. Purpose of this trip?

١٣ - الغرض من الرحلة

- Business

- عمل

- Leisure/
Vacation

- اجازة

- Others

- غير ذلك

14. Monthly Income Group?

١٤ - الدخل الشهري ؟

- Below SR 5000

- اقل من ٥٠٠٠ ر.س

- SR 5000-10000

- بين ٥٠٠٠ - ١٠٠٠٠ ر.س

- SR 10000-15000

- بين ١٠٠٠٠ - ١٥٠٠٠ ر.س

- More than 15000

- اعلى من ١٥٠٠٠ ر.س

Thank you for your cooperation!

شاكراين تعاونكم ..

5.4 SURVEY METHODOLOGY:

This section describes the method including survey execution, sample size and flights surveyed, questionnaire processing and results analysis.

5.4.1 Survey Execution:

Passengers are interviewed in the departure lounge (domestic or international) after completion of all airport departure requirements; check-in, immigration and customs. During this time the passenger is ready to discuss his views more freely because the passenger has completed the departure process and is ready to travel.

Although at this time the passengers are free but survey interviewing is constrained in such a way that most of the passengers come to the departure lounge at almost the same time which makes it difficult to interview many passengers from the same flight. The average survey time is 10 minutes but sometimes it takes longer because the passengers discuss issues on airline services, schedule changes, punctuality, etc.

The interviews were conducting interactively and most of the questions and possible answers were presented to passengers in cards both in Arabic and in English. Depending on the nature of the question a passenger responds with one answer or multiple answers i.e. question (8) of this questionnaire where passenger gives one answer but in question (9) passenger can give more than one answer depending on his opinion.

5.4.2 Sample Size:

As a feedback from the pilot survey, it was decided to cover both international and domestic passengers traveling from Jeddah. So a total number of *262 passengers are surveyed during four weeks by one person*. The flights surveyed covers flights departing during day times and flights departing during night times. These flights cover many markets in domestic regions with flight length of 45 minutes and of two hours. 96 passengers were surveyed in domestic flights. Similarly, in international regions passengers leaving to Europe, North America, Middle East, Africa, Far East and Gulf were surveyed. 166 international passengers were surveyed in international flights.

5.4.3 Processing:

All survey responses are coded after completing interviews of total sample size. A database is structured using dbase III+ system. All survey responses are entered into the database file. The database is reviewed to check the accuracy of data entry. Then the survey data file is transferred to text file and up loaded to mainframe for statistical analysis. In the mainframe environment, "SAS" System is used for analysis and cross tabulations. Programs are written for processing and analysis of survey data (61). One main program which reads the row data and assigns variable names to data elements. Variable labels and variable formats are defined for each variable, so the SAS procedure can be used.

Other programs are written for data analysis as required to distinguish different relationships among the survey variables. Procedure Frequency "PROC FREQ" is used with Procedure Sort "PROC SORT" as required to sort by other variables. 'TABLES' command is used in the Procedure Frequency for generation of the cross-tabulation tables for different variables.

PROC FREQ:

```
TABLES      (SAT DLY CXL) * (NAT PURPOS);
```

```
FORMAT      SAT          SATISFY - F.  
            DLY          DELAY - F.  
            CXL          CANCEL - F.  
            NAT          NATIONALITY - F.  
            PURPOS       PURPOSE - F;
```

```
LABEL      SAT = SATISFIED WITH SAUDIA PUNCTUALITY  
            DLY = YOUR ACTION IN CASE OF DELAY  
            CXL = YOUR ACTION IN CASE OF CANCELLATION  
            NAT = NATIONALITY  
            PURPOS = PURPOSE OF YOUR TRIP;
```

The above is an example of using procedure frequency in multi-variable cross-tabulations, i.e. in the above example three variables SAT, DLY and CXL are cross tabulated with passenger's nationality and trip purpose. Then six tables are produced which represent SAT with nationality, SAT with trip purpose, DLY with nationality, DLY with trip purpose, CXL with nationality and CXL with trip purpose. Some of the SAS programs that are used for the survey analysis are included in Appendix (B).

5.5 RESULTS AND ANALYSIS:

Results includes passengers demography, general analysis and in-depth analysis of all survey variables. Six variables are analyzed and results of the general and in-depth analysis are shown. This includes current satisfaction level, delay impact with five different delay times between 1/2 hour to 6 hours. Passengers' action in case of delay, delay compensation, influence of delays on future airline selection and passenger action in case of cancellation.

5.5.1 Passengers Demography:

Three major variables are considered in the demography as designed in the survey: nationality of passengers, purpose of trip, and passengers monthly income group.

(a) Nationality:

ARABS (including SAUDIS)	83.0%
WESTERNERS	14.5%
ASIANS	2.5%

(b) Purpose of Trip:

Business	49.0%
Leisure/vacation	34.0%
Others	17.0%

(c) Monthly Income Group:

Income is represented in terms of Saudi Riayals (SR).

Below SR 5000	26.7%
SR 5000 - 10000	33.2%
SR 10000 - 15000	18.7%
More Than SR 15000	21.4%

5.5.2 Current Passengers Satisfaction with Punctuality:

- | | | |
|-----|---------------------------|----------------|
| (a) | <u>Satisfaction Level</u> | <u>Percent</u> |
| | Not satisfied | 19.8% |
| | Satisfied | 51.2% |
| | Highly satisfied | 29.0% |
- (b) About 20% are not satisfied compared to 80% who were satisfied and highly satisfied.
- (c) 21.2% of ARABS are not satisfied compared to 8% of WESTERNERS.
- (d) About 27% of business passengers are not satisfied with punctuality compared to only 12% vacationers.

5.5.3 Delay Impact:

a) General Delay Impact:

The general delay impact represents all passengers including business and vacationers. Table 5-1 shows the percentage of passengers who are impacted from flight delays. Five levels of impact including zero impact, very slight impact, slight impact, serious impact and very serious impact. Five levels of delay time also are measured as discussed in details in the front part of this chapter including delays for 0.5 hour, 1 hour, 2 hours, 4 hours and 6 hours. Then the weighted average of the passengers impact are found for all delay levels. As shown in table 5-1 that no impact has a weight of 1, very slight impact has a weight of 2, slight impact has a weight of 3, serious impact has a weight of 4 and very serious impact has a weight of 5.

Table 5-1 Percentage response for different delays

Impact	1/2 h	1 h	2 h	4 h	6 h
1. No	47.0	14.1	4.2	2.8	2.8
2. V.Slight	9.2	11.1	1.2	0.8	-
3. Slight	27.5	30.5	13.8	0.8	-
4. Serious	9.9	21.0	28.2	13.6	2.4
5. V.Serious	5.0	21.0	51.2	82.0	94.6
Wtd.Avg.Imp:	2.13	3.17	4.17	4.71	4.85

Table 5-1 shows the percentage of passengers who respond 'very serious impact' increases as delay time increases. **Figure (5-2)** shows the average delay impact for all passengers. It can be seen that the more delay time the higher the average impact on passengers.

(b) Delay Impact for Business Passengers:

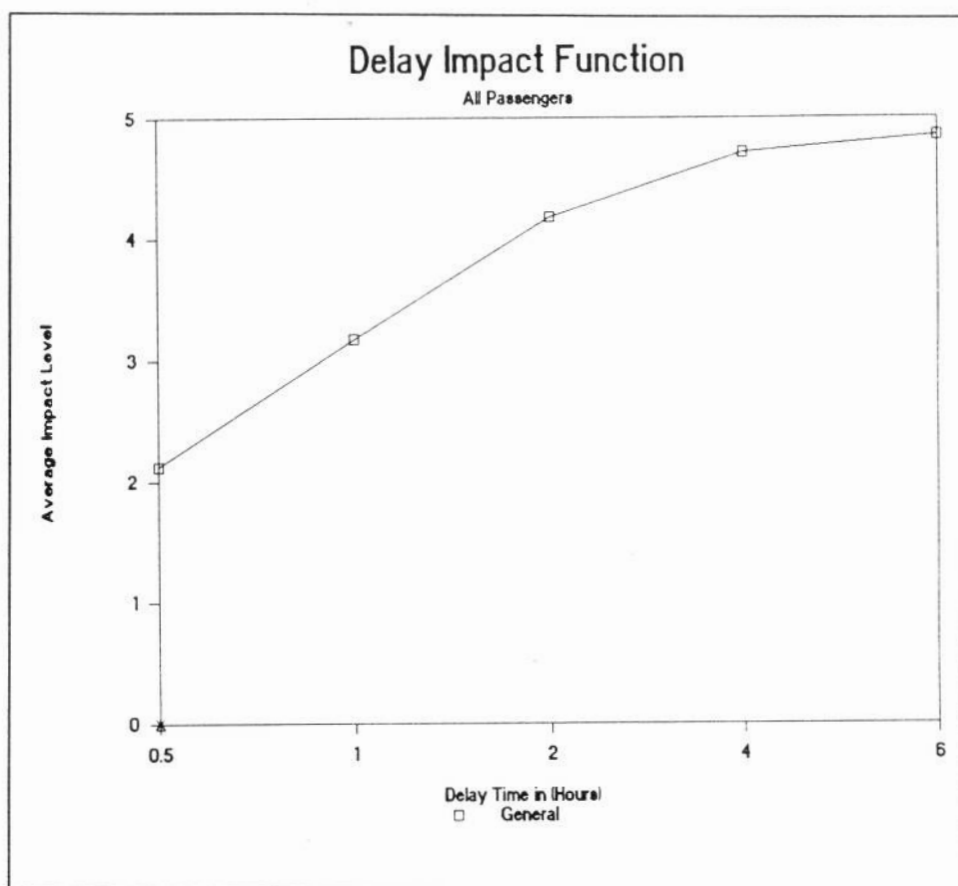
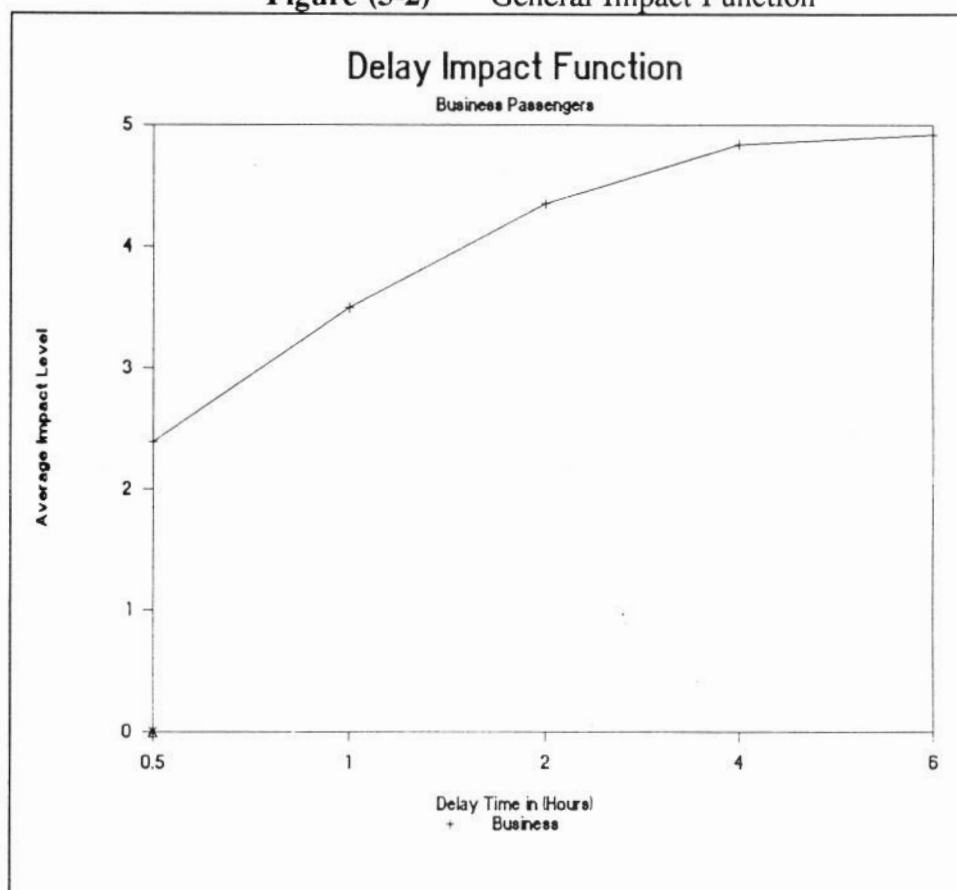
Table 5-2 illustrates the percentages of business passengers impact.

Table 5-2 Percentage response for different delays

Impact	1/2 h	1 h	2 h	4 h	6 h
1. No	38.3	7.8	1.6	1.6	1.6
2. V.Slight	9.4	9.4	-	-	-
3. Slight	29.7	29.7	10.2	-	-
4. Serious	16.4	23.4	31.3	8.9	0.8
5. V.Serious	5.5	28.1	55.5	89.4	97.4
Wtd.Avg.Imp:2.39	3.50	4.35	4.84	4.92	

The percentages of business passengers who respond serious and very serious impact are higher than the percentages of all passengers impact appears in table 5-1. Even for short delays of 0.5 or 1 hour business passengers are greatly impacted. About 22% of business passengers who respond 'serious and very serious impact' for 0.5 an hour delay compared to 15% of all passengers. 51.5% of business passengers who respond 'serious and very serious impact' for 1 hour delay compared to 42% of all passengers.

Figure (5-3) illustrates the average impact for business travellers impact function. It is noticeable that the average impact value of business passengers for the five delay levels are higher than the average impact of all passengers.

**Figure (5-2)** General Impact Function**Figure (5-3)** Business Impact Function

c) Delay Impact for Leisure/Vacation Passengers:

Table 5-3 illustrates the percentage of leisure/vacation passengers who are impacted by delays.

Table 5-3 Percentage response for different delays

Impact	1/2 h	1 h	2 h	4 h	6 h
1. No	53.9	22.5	6.7	4.5	4.5
2. V.Slight	10.1	9.0	-	-	-
3. Slight	25.8	34.8	16.9	1.1	-
4. Serious	2.3	16.9	30.3	16.8	1.1
5. V.Serious	5.6	14.6	46.1	75.3	91.0
Wtd.Avg.Imp:1.89 2.85 4.10 4.52 4.64					

The percentages of vacationers who respond 'serious and very serious impact' are much less than the percentages of business and all passengers impact table 5-2 and table 5-1 respectively. About 8% of vacationers who respond 'serious and very serious impact' for 0.5 an hour delay compared to 22% business passengers compared to 15% of all passengers. 31.5% of vacationers who respond 'serious and very serious impact' for 1 hour delay compared to 51.5% of business passengers compared to 42% of all passengers.

Figure (5-4) shows the average impact function for leisure passengers and vacationers. It is noticeable that the average impact values of vacationers are less than the average impact of all passengers and much less than the average impact of business passengers.

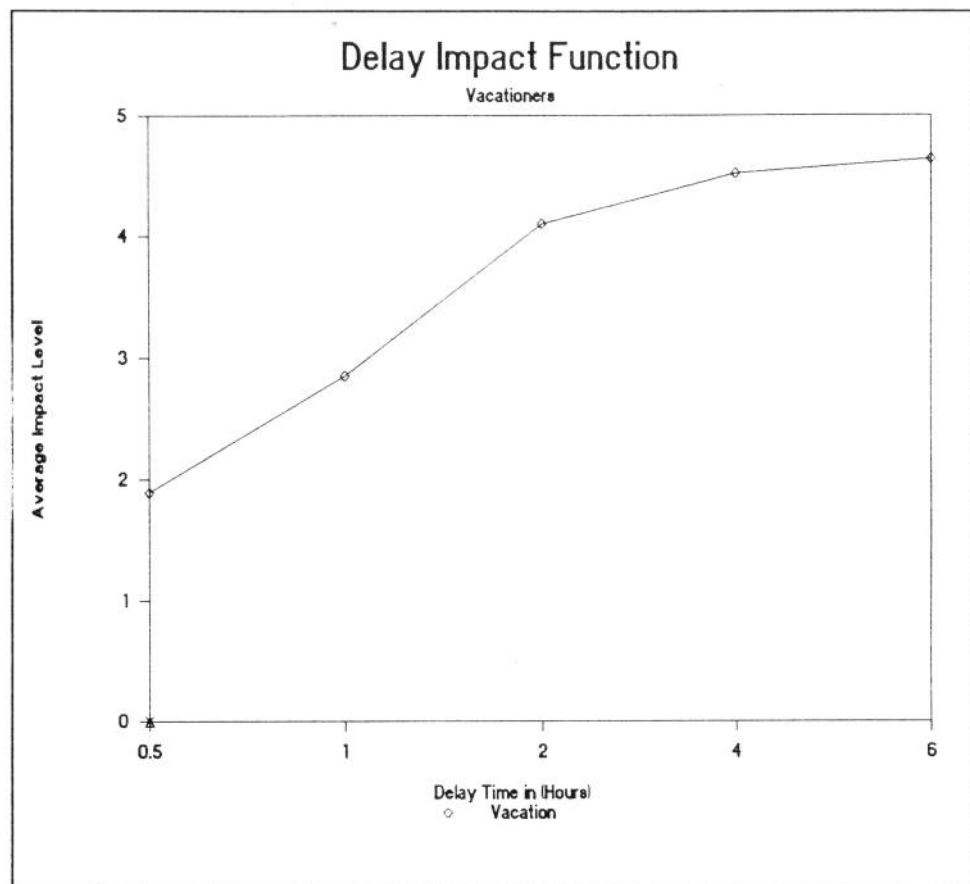


Figure (5-4) Vacationers Impact Function

Delay Impact Functions Summary:

A comparison chart in figure (5-5) shows a comparison of the average *delay impact functions* related to passengers' trip purpose. The Chi-square test is applied to all impact functions to test if they differ significantly from the general impact function. The middle curve represents the general delay impact, the top curve represents the business impact function and the lower curve represents the vacationers impact function. This concludes that the results of survey analysis are plausible because normally business travellers are highly impacted by schedule delays and cancellations.

The chi square tests shows that all impact functions are not significantly different from the general impact function. Chi square value for business is 0.0713 and for liesure impact is 0.0851. While the critical chi square value for 0.01 level of significance (alpha) and 4 degrees of freedom (n) is 7.779.

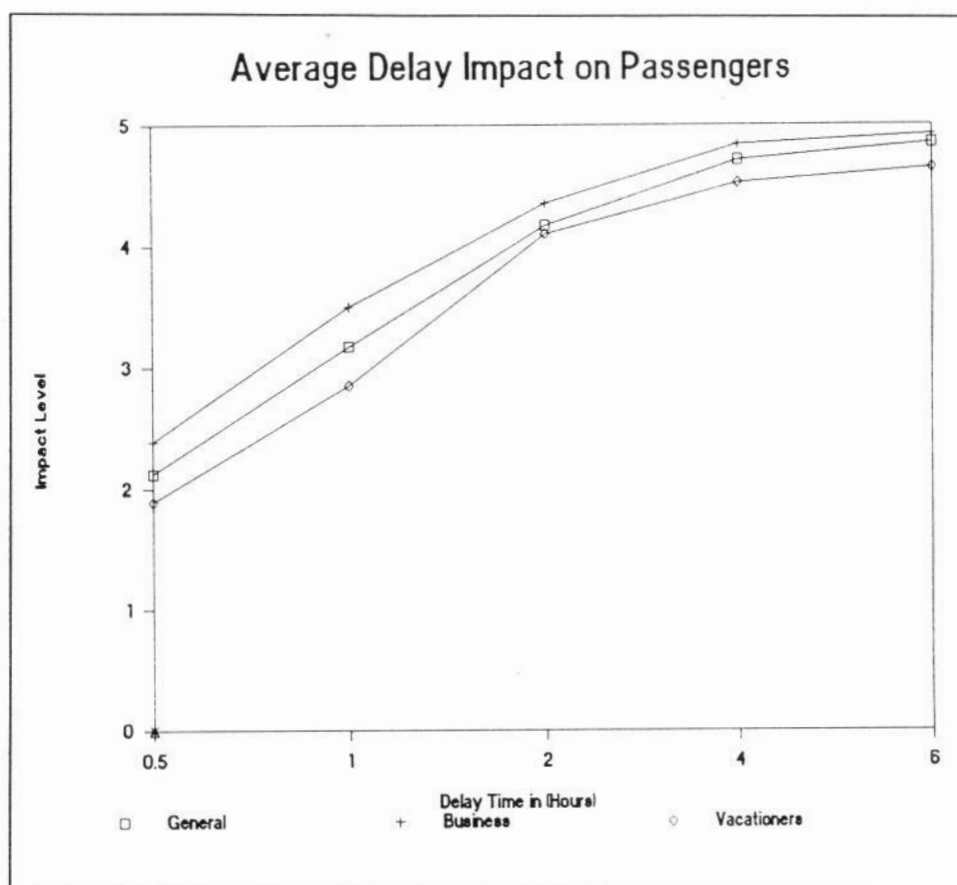


Figure (5-5) Delay Impact Functions

(d) Delay Impact for Domestic Passengers:

For the purpose of identifying the delay impact of the domestic passengers including all types of passengers (business and vacationers), table 5-4 shows the percentage of the domestic passengers who are impacted for five delay levels.

Table 5-4 Percentage response for different delays

Impact	1/2 h	1 h	2 h	4 h	6 h
1. No	38.5	11.5	3.1	1.04	1.2
2. V.Slight	12.5	12.5	3.1	2.3	-
3. Slight	30.2	33.3	15.6	1.04	-
4. Serious	12.5	18.8	31.3	20.7	3.7
5. V.Serious	6.25	19.8	44.8	74.7	95.1
Wtd.Avg.Imp:2.35	3.11	4.05	4.65	4.92	

About 19% of domestic passengers who respond 'serious and very serious impact' for 0.5 an hour delay compared to 15% of all passengers. About 39% of business passengers who respond 'serious and very serious impact' for 1 hour delay compared to 42% of all passengers.

(e) Delay Impact for International Passengers:

Table 5-5 shows the percentages of international passengers.

Table 5-5 Percentage response for different delays

Impact	1/2 h	1 h	2 h	4 h	6 h
1. No	51.8	15.7	4.8	3.6	3.6
2. V.Slight	7.2	10.2	-	-	-
3. Slight	25.9	28.9	12.7	.6	-
4. Serious	8.4	22.3	26.5	9.6	1.8
5. V.Serious	4.2	21.7	54.8	84.3	93.4
Wtd.Avg.Imp:1.98	3.21	4.23	4.65	4.78	

About 13% of international passengers who respond 'serious and very serious impact' for 0.5 an hour delay compared to 19% of domestic passengers and 15% of all passengers. 44% of international passengers who respond 'serious and very serious impact' for 1 hour delay compared to 39% of business passengers and 42% of all passengers.

Domestic passengers are impacted more with short delays because most of the domestic flight are short ranges flights although in most cases there are multiple flights daily. International passengers are impacted more with longer delays.

Figure (5-6) gives a comparison of average impact functions for domestic, international and system passengers.

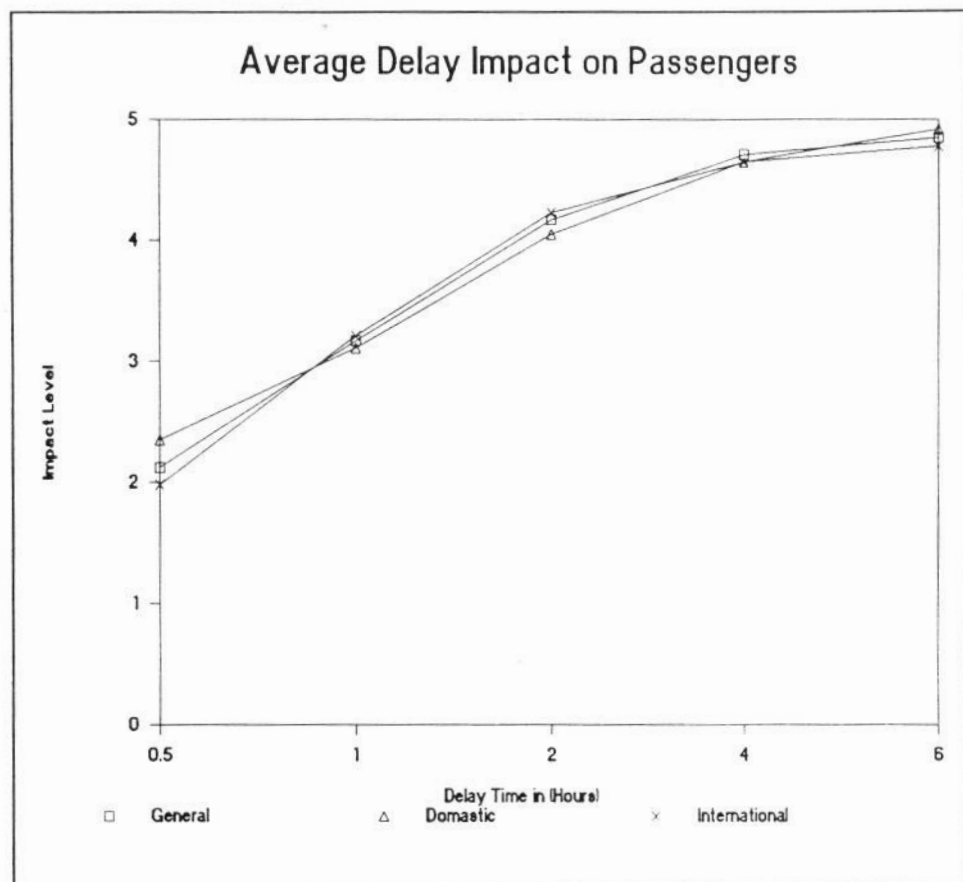


Figure (5-6) Impact Function by Division

The chi square tests shows that all impact functions are not significantly different from the general impact function. The chi square value for domestic impact is 0.0271 and for international impact is 0.0145. While the critical chi square value for 0.01 level of significance (α) and 4 degree of freedom (n) is 7.779.

5.5.4 Action in case of Delay:

The following is the analysis of passengers actions in case of delay time which impact them seriously. The question regarding action in case of delay is asked with delay time of two hours to enable passengers to respond precisely.

- (a) Four possible actions are considered that passengers may adopt. Either stay waiting until flight is ready or come for the next flight or cancel the flight and find another alternative or cancel the trip. Table 5-6 shows the percentages of passengers who adopt those actions. Passengers including all passengers, business and leisure passengers.

Table 5-6

	<u>General</u>	<u>Business</u>	<u>Leisure</u>
Stay Waiting	61.5%	54.7%	69.7%
Come for Next Flight	14.5%	18.0%	10.1%
Cancel/Find alternative	18.7%	18.8%	16.9%
Cancel the Trip	5.3%	8.6%	3.4%

Percentage of leisure passengers are the highest percentage (69.7%) who stay waiting for the flight compared to 54.7% for business passengers. On the other hand business passengers are more likely to come for the next flight (18%) and 18.8% of them will cancel and find an alternative.

About 45% of business passengers will not stay waiting compared to 30% of leisure passengers.

- (b) About 24% of all passengers said that they would cancel the trip and those who said cancel this flight and other alternative are considered as a passenger revenue loss. The passenger revenue loss percentage for business travellers is 27.4% and for vacationers is 20.3%.
- (c) Passengers actions in case of delays in domestic and international markets are shown at table 5-7. About 67% of international passengers and 52% of domestic passengers will wait for the flight until it is ready. The difficulties in travel rearrangement might be one of the factors which make the international percentage higher than the domestic.

Table 5-7

	<u>DOM PASSENGERS</u>	<u>INT'L PASSENGERS</u>
Stay waiting until flight is ready.	52.1%	66.9%
Come for next flight	17.7%	12.6%
Cancel and find alternative.	21.9%	16.9%
Cancel this trip	8.3%	3.6%

- (d) Passengers revenue loss is 30.1% of domestic passengers and 20.5% of international passengers. This is the result of the effect of the availability of other means of transport and the effect of short stage length.
- (e) There is no significant difference in these percentage losses with nationalities of passengers. The percentage loss in international markets is Arabs 20.2% and Westerners 18.4%.
- (f) For those passengers who say "stay waiting until the flight is ready" as an action in case of flights delay, the following are percentages of passengers who are seriously and very seriously impacted.

<u>Delay Time</u>	<u>% of PASSENGERS who are seriously and Very Seriously Impacted</u>
1/2 hr.	13.6%
1 hr.	45.3%
2 hrs	79.5%
4 hrs	90.0%
6 hrs	91.0%

- (g) The percentage of 'stay waiting' passengers who are seriously and very seriously impacted according to their trip purposes. 54.3% of business passengers and 38.3% of leisure passengers who respond 'stay waiting' for a delay of one hour are seriously and very seriously impacted.

Table 5-8

% of PASSENGERS who are seriously and <u>Very Seriously Impacted</u>		
<u>Delay Time</u>	<u>Business</u>	<u>Leisure</u>
1/2 hr.	21.4%	6.4%
1 hr.	54.3%	38.3%
2 hrs	87.2%	80.6%
4 hrs	94.2%	93.5%
6 hrs	98.5%	93.5%

5.5.5 Compensation in case of Delays:

- (a) As mentioned earlier delays are not avoidable but airlines can reduce the impact of these delays on the passengers by providing them with compensation i.e. food and beverages, telephone services, family and mother care facilities and financial compensation. Table 5-9 shows the percentages of total passengers (262 passengers surveyed) who select these compensations.

Table 5-9

<u>Compensation</u>	<u>% of Passengers</u>
Food/Bev	69.0%
Telephone Services	56.0%
Family/Mother care	46.6%
Financial Comp	4.9%
Others	9.9%

- (b) The most suitable compensation for passengers is providing food and beverages (69%), provide telephone services (56%) and family/mother care facilities (46.6%).
- (c) Financial compensation is considered as a suitable delay

compensation for a minority of the passengers. Only 4.9% of the sample size think it is suitable due to the fact that most of passengers believe that any airline operations are subject to delays. Technical and operation oriented delays are excused by most of the passengers provided that airlines inform them about the delay and impact will be lower if suitable compensation is provided.

5.5.6 Delay Influence on Future Airline Choice:

(a)	<u>Influence Level</u>	<u>% of PASSENGERS</u>
	No Influence	24.8%
	Some Influence	17.2%
	Great Influence	33.2%
	Missing	24.8%

Missing values represents the opinion of domestic passengers where Saudia is the only airline. Passengers in this case cannot choose another airline.

- (b) Future influence on international passengers considering competitive influence percentages are higher:

<u>Influence Level</u>	<u>% of Int'l PASSENGERS</u>
No Influence	33.0%
Some Influence	22.8%
Great Influence	44.2%

- (c) About 67% of international passengers are influenced in their future airline choice.

- (d) Influence on future airline choice for competitive markets for both business and vacationers are:

	<u>Business</u>	<u>Vacationers</u>
No Influence	24.0%	41.5%
Some Influence	21.0%	24.6%
Great Influence	55.0%	33.9%

- (e) About 76% of the business passengers and about 58% of vacationers will be influenced by a delay of two hours. As discussed with passengers during the interviews, the influence will be greater in case of frequent delays.

5.5.7 Action in case of cancellations:

- (a) Three actions were available for passengers in this survey. About 43% of passengers will come for the next flight and about 56% of passengers will find an alternative or cancel the trip.

Come for the next flight	42.8%
Find alternative OAL/CAR	50.8%
Cancel the trip	5.3%

- (b) Action in case of cancel by purpose:

	<u>Business</u>	<u>Vacationers</u>
Come for next flt	35.9%	44.9%
Find alternative	55.5%	49.4%
Cancel the trip	6.3%	5.6%

5.5.8 Revenue Loss Functions:

The objective of this section is to estimate the general revenue loss function for both types of passengers considered here; business passengers and vacationers.

Section 5.5.3 developed the delay *impact functions* from passengers' input to the survey. Figure 5-2, 5-3 and 5-4 show the impact functions for all passengers, for business passengers and vacationers respectively. As discussed the impact functions relates delay impact level and delay time. As noticed from all the impact functions the higher the delay time the higher the passenger's impact. There is a maximum impact limit which a higher delay time would not exceed. This reflects the behaviour of the impact function at high delay times where the impact function increases slowly. So a maximum impact level approaches impact value of 5 'very serious impact'. The average impact value for a delay of 6 hours is 4.85 for all passengers, 4.92 for business passengers and 4.62 for vacationers. On the minimum side, similarly the impact of a very short delay time (less than half an hour) would not have a significant impact on passengers.

As defined at the beginning of this chapter:

- A = Maximum delay time where delay has zero impact on passengers.
- B = Delay time where delay has a maximum impact on passengers.
- C = Maximum percentage loss of passengers revenue with delay time of B.

Albert of Eastern Airlines formulate the loss function as an upward sinusoidal function (ALBERT (59)).

In this case the behaviour of the general impact function developed from the survey analysis will be used for developing the loss function. This is based on two factors; the impact function has an upward trend which relates delay time with impact level. The second is the assumption **that there is a linear relationship between passengers revenue loss and delay impact**. This means that as delay impact increases, the percentage of revenue passenger loss increases too. Then the revenue loss function behaviour is similar to the delay impact function with maximum revenue loss value (point C) equal to the revenue loss percentage determined from the survey in section 5.5.4. The value of maximum delay time where delay has zero impact (point A) is 0.5 hour. The value of delay time which has maximum impact (point B) is 6 hours as evaluated in the survey.

Then revenue loss function will equal zero for any delay less than point A (0.5 hour) and equal to the maximum revenue loss for any delays equal or greater than point B (6 hour), in between revenue loss function is normalized to the maximum revenue loss percentage using the impact function behaviour.

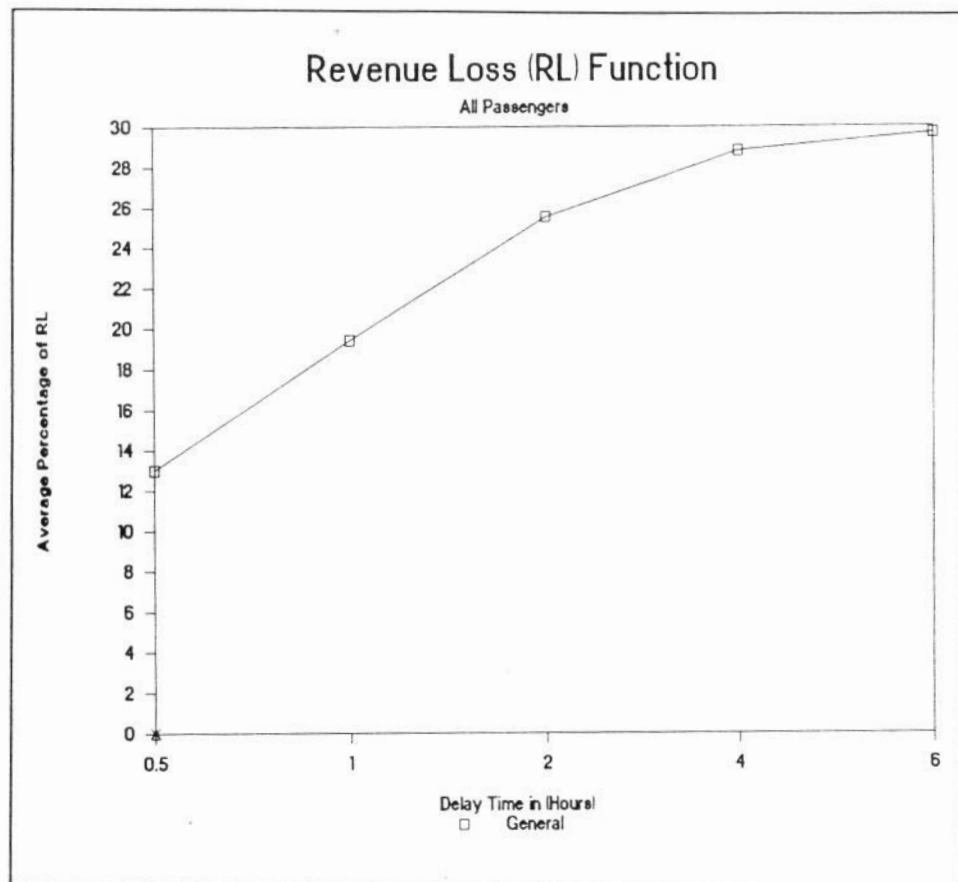
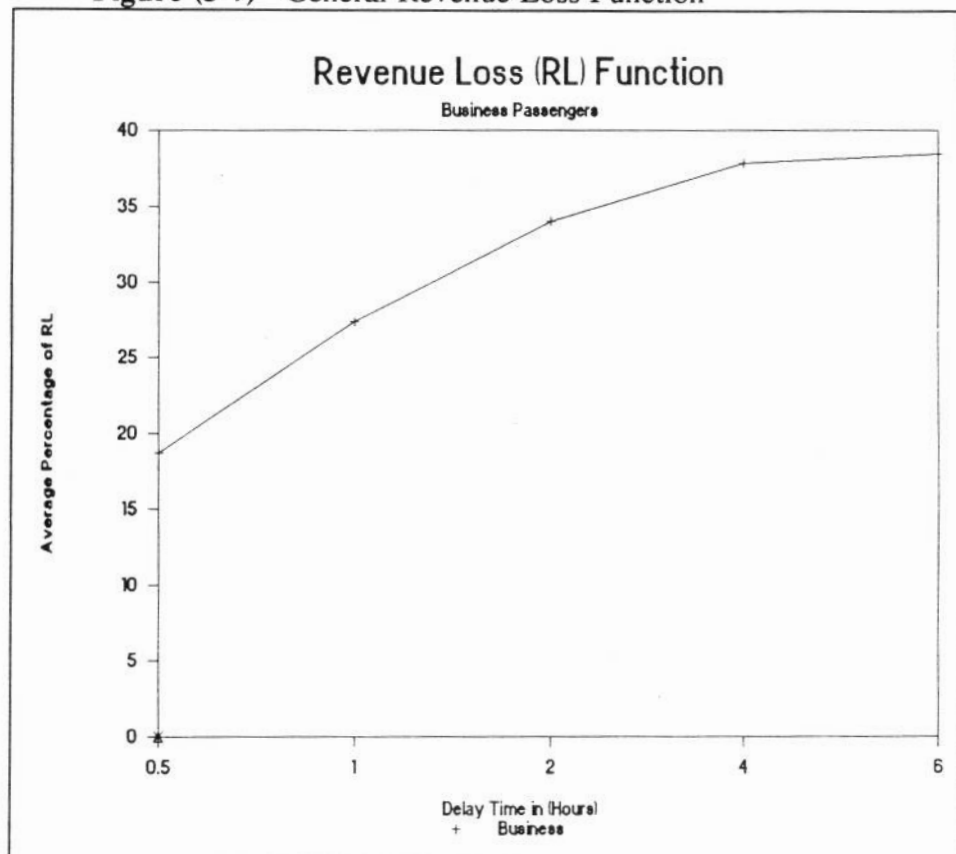
Passenger revenue loss is approximately 24% of *all passengers* in case of two hours delay duration as appears in **figure (5-7)** and about 13% revenue loss in case of 0.5 hour delay duration. On the other hand there are some passengers who prefer to stay waiting for flight delays but they are seriously/very seriously impacted, those may also be lost in future. 13.6% of all passengers declared that they would stay waiting for the flight when 0.5 hour delay occurred but they are seriously and very seriously impacted. Considering 44% of passengers are greatly influenced in their future airline choice when there are frequent delays. Assume that this 0.5 hour delay occurs frequently then about 44% of the 13.6% passengers are expected to be lost in future which is 6.6% of all passengers.

Therefore the percentage revenue loss varies in the range of 13% to 19.9% for 0.5 hour delay time. 13% is found similarly for *business passengers* revenue loss varies in the range of 18.8% to 30.5% for 0.5 hour delay time. For *leisure and vacationers* revenue loss varies in the range of 9.4% to 13.9% for 0.5 hour frequent delays.

This approach approximates the percentage revenue loss based on passengers' responses during the survey. Clearly passengers attitude might change from time to time depending on many factors. 24% of all passengers will be lost in the case of 2 hours delays, but practically speaking those passengers who said they will cancel the flight or the trip or go to other means, some will come back and surely some will be lost in the future. In other words there will be revenue trip loss and passenger revenue loss. Although passengers will come back to the airline later the airline loses their revenue on those trips.

The survey as it stands cannot estimates the response of passengers over time and in particular their return to the airline if punctuality improves. This is a weakness of using the maximum revenue loss function the way it is currently in the rest of the analysis particularly in the revenue model. It is understandable that it requires more research to determine exactly the revenue loss percentage.

Figures 5-7, 5-8 and 5-9 shows the general, business and leisure passenger revenue loss functions respectively.

**Figure (5-7)** General Revenue Loss Function**Figure (5-8)** Business Revenue Loss Function

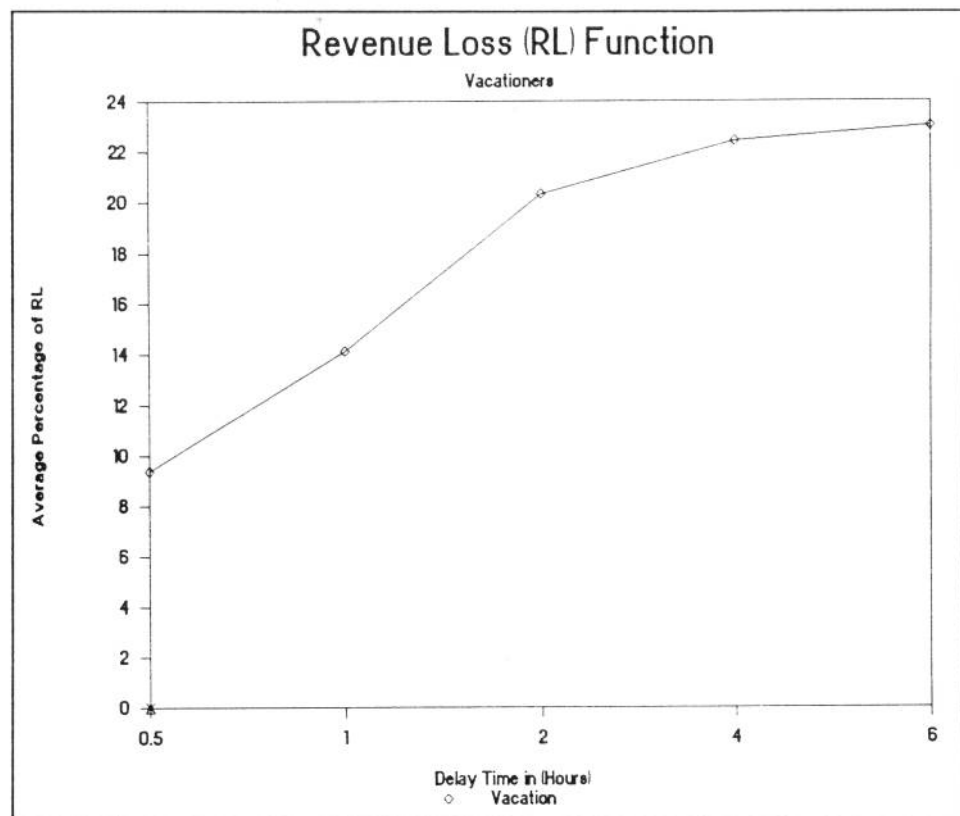


Figure (5-9) Vacationers Revenue Loss Function

5.6 SURVEY FINDINGS:

The average impact functions chart appears in figure (5-5). It relates the impact function to passenger's trip purpose. Three curves, the middle curve represents the general delay impact, the top curve represents the business impact function and the lower curve represents the vacationers impact function. This suggests that the results of survey analysis are plausible because normally business travellers are highly impacted by schedule delays and cancellations.

A comparison of the *passenger revenue loss* functions shown in figure (5-10) relate revenue loss to passenger's trip purpose. Similar findings, to the delay impact, are found here where the middle curve represents the general revenue loss, the top curve represents the business revenue loss function and the lower curve represents the vacationers revenue loss function. Business passengers who are lost are always higher than general and vacation passengers.

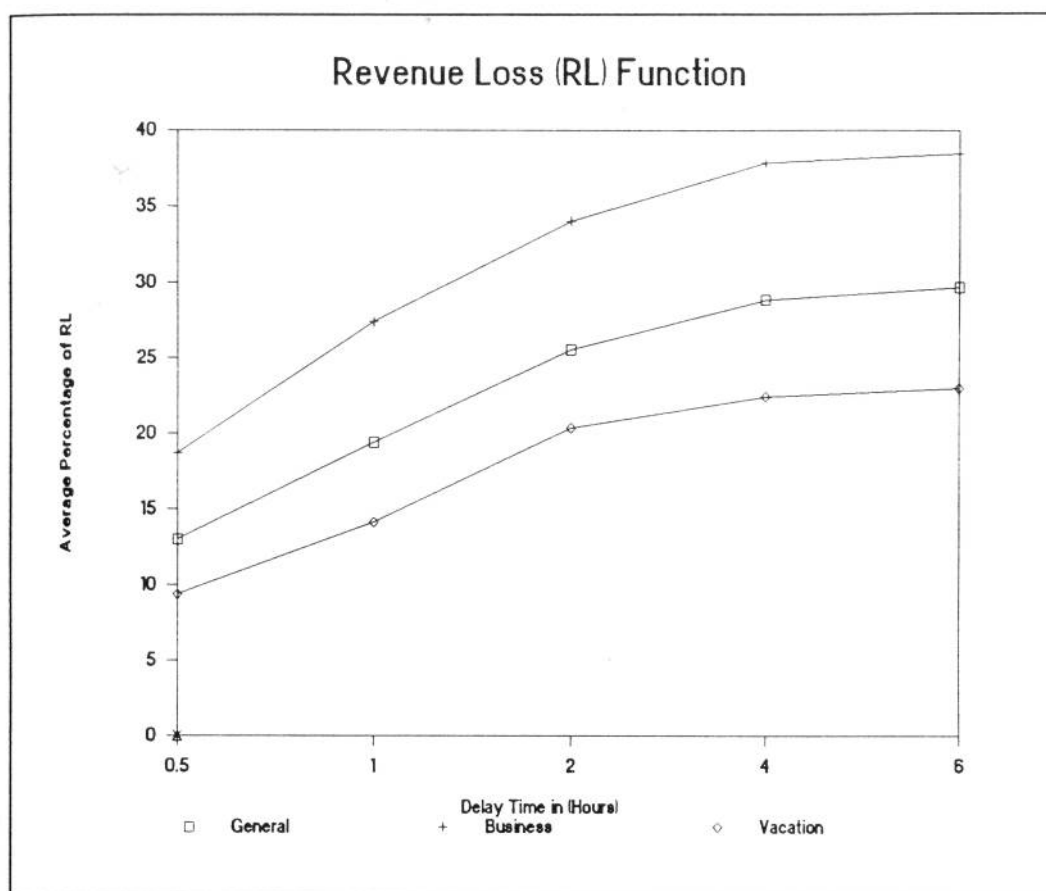


Figure (5-10)

Revenue Loss Functions

Chapter (6)

AIRCRAFT SCHEDULE SIMULATION

MODEL (SKDMOD)

Airline Punctuality Management is a complex issue due to the overlapping and inter connecting activities so the analytical approach can not always be feasible with high level of realism and practicality. Therefore a simulation approach may need to be adopted to provide management with a satisfactory decision support tool.

This chapter illustrates in section 6.1 the objectives of Aircraft Schedule Simulation Model [SKDMOD] and gives some information on the previous work in this area and the differences in SKDMOD. Section 6.2 describes the background to simulation and the application of Simscript II.5 in schedule simulation.

Section 6.3 discusses in details the SKDMOD model building including the logic diagram and sub-models built in the model. Section 6.4 discusses the SKDMOD Simscript II.5 programming and development including a description of the model scope, assumptions undertaken during development, model flow diagram and structure. Section 6.5 shows the input required for SKDMOD. Section 6.6 describes the output reports which are generated from the model.

Section 6.7 demonstrates the application of SKDMOD using a regional Schedule Plan for "B737" aircraft. Data requirement and simulation results are discussed and analyzed in the same section.

The SKDMOD program listing is enclosed in Appendix d.

6.1 INTRODUCTION:

The airline Schedule Simulation Model [SKDMOD] is a prototype simulation model of management decisions concerning punctuality using an airline flight schedule plan in which flights and aircraft are simulated with original delay factors to determine the reactionary delay inherent in the schedule and consequently the overall punctuality performance. As mentioned earlier in Punctuality Management Structure "Chapter 2" original delays cause a disturbance in the schedule plan and these might propagate in the entire

schedule.

Schedule disturbances are caused from either internal or external factors. Different internal and/or external disturbance causes are described in details in Appendix (A). Delays are analyzed in Chapter 3 and delay distribution functions are estimated in Chapter 4.

SKDMOD addresses the core portion of the punctuality management system Structure (section 2.5) in an integrated model where all the models involved in punctuality management system are addressed. The models involved are disturbance model, recovery model, cost and revenue models. For quick reference the diagram which shows the overall structure of punctuality management is shown in **figure (6-1)**.

SKDMOD uses flight schedule plans and airline system components including active and spare fleet as input. Total delay time including original and reactionary delays are the output. Schedule punctuality level and utilization of spare aircraft used for Punctuality Management are also outputs from SKDMOD. The total delay time is used in the passenger attitude model to determine the level of impact in case of delays. The impact level indicates the expected percentage loss of revenue. Spare aircraft and hours performed by spare aircraft are used to determine the extra cost of punctuality.

Figure (6-1) explains that operating revenue loss, extra operating cost and punctuality performance level are output variables for this system. Slack times, aircraft including utilization factors and airline resources such as manpower crews and reliability standards are possible decision variables. A rectangular shape represents a system entity and a circular shape represents a model. Detailed descriptions of the overall system are mentioned below and details of the models are discussed in detail in chapter (2).

Implementation of the schedule plan with slack times in flight block times and/or in aircraft ground times, using the system resources (aircraft, equipment and crews) will generate some schedule disturbances. These disturbances are in the form of aircraft delays. Operations and marketing try to eliminate such delays by taking different corrective actions as appropriate. These actions can be *deviation of other aircraft, substitution of different types of aircraft or employment of more crews*. In spite of these corrective actions some flights will still have to be delayed. So *total delay time* becomes a result of the recovery actions using airline resources including *spare aircraft* and slack time.

The delay time *influences passengers' future behaviour* on selecting airlines. Naturally this impact varies according to the length of delay time and to the services presented to passengers while waiting. Again this impact differs from business travellers to vacationers. In any case this will affect the operating revenue due to *passengers loss*. On the other hand *extra operating cost* is suffered due to these extra activities and facilities resulting from a recovery of

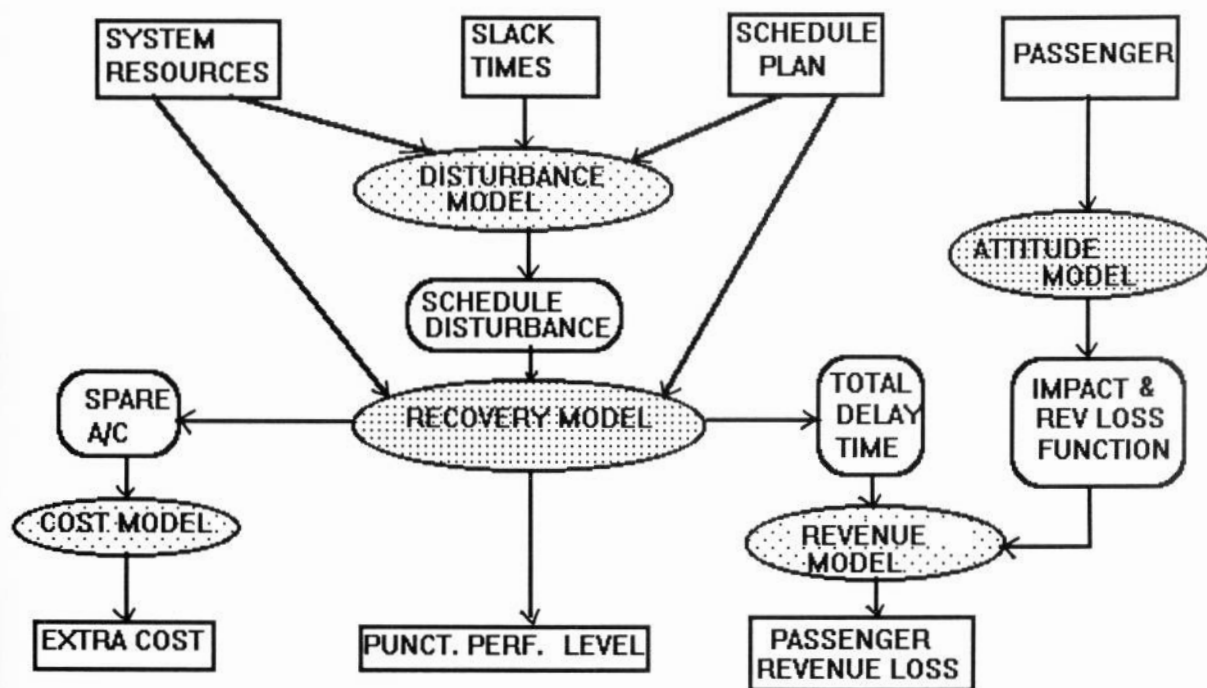
flight delays.

Previous work on schedule punctuality concentrated on developing analytical or simulation models. The scope of these models was greatly simplified due to different reasons including unavailability of a systematic method for gathering reliability data. Some simulation models ignore weather disturbances. All of previous simulation models are classified into two groups; the first group considered the assignment to the schedule is predetermined and fixed whatever series disturbances exist, and the second group assumed no prior assignment has been given to flights and during flight dispatch the aircraft assignments will be given according to the situation. Because the first group represents aircraft cycles/rotations this type of simulation is called *Cycle Simulations* and the second group is called *Aircraft Assignment Simulations*.

Details of the previous work in the schedule simulation is discussed in Chapter 1 section 6.

The above mentioned models and studies focus only on solving a management problem such as determination of required number of spare aircraft and schedule delays. On the other hand this research focuses on the whole schedule punctuality management including the decision making process and strategies involved. So a schedule simulation model will be developed based on a *simplified* delay model to demonstrate implications of airline management in the punctuality decision making using PC Simscript II.5 simulation language on microcomputer.

Figure (6-1) Punctuality Management System Structure



6.2 SIMULATION AND SIMSCRIPT II.5:

When building a model for any system, the relationships among different parts of the system have to be derived and formulated. If these relationships which compose the system are simple then it might be possible that a mathematical approach can be adopted to obtain a solution for this system. This is called the **analytical approach**. However, most of real world systems are too complex to allow realistic models to be solved analytically, so these models must be approached by means of **simulation**.

Simulation models can be physical and/or mathematical. A *Physical simulation* model is a physical representation of object but in a prototype form such as an airplane model in a wind tunnel where all aerodynamic experiments are simulated and the performance is monitored. Other types of simulation models can be based on the development of a mathematical representation of the real system. Then this representation is modeled in a computer using high level programming language or general purpose simulation languages.

Simulation models can be static or dynamic according to the nature of the system. A *static* simulation model is a representation of system at a particular point of time such as Monte Carlo Simulation Model. A *dynamic* simulation model is a representation of a system as it evolves over time such as activities over a period of time. (LAW (62))

Simulation models can be deterministic or stochastic. A *deterministic* simulation model does not contain random variables. There is one unique output for a given set of input. This output would not change. On the other hand a *stochastic* simulation model has at least one or more random variables. The output of stochastic models themselves are random. (LAW (62))

In Airline Punctuality Management the system is a complex system in which the simulation approach is one which will be capable of representing the airline operations with a high level of realism and practicality. Since in this model punctuality management system has random delays (disturbance) then SKDMOD is a *stochastic simulation* model.

Aircraft Schedule Modeling is stochastic type of model which dynamically changes with time so the numerical approach is intractable. (ETSCHMAIER AND ROTHSTEIN (63)) mentioned that numerical convolution requires discretizing of the density functions in small intervals which will lead to high computation time, all variables have to be performed in parallel because there is interdependence between variables. The method of numerical convolutions is relatively rigid as compared to the state of art of simulation where the programming effort is kept to minimum.

Simulation systems used for system's modeling are categorized as discrete or continuous or both. Some of these systems are general purpose simulation systems and some are special purpose simulation systems.

Recently, due to the advances in PC hardware technology some of the major simulation packages have been developed for a PC system from mainframe simulation packages. Animation of the simulation system becomes a new additional capability of these PC's simulation packages. That provides a major improvement to the graphical presentation of simulation results.

The four most popular mainframe simulation packages have been "brought down" to the microcomputer. All four are technically sound implementations. In general, SIMAN and SLAM II PC are still more mainframe-oriented than GPSS/PC and SIMSCRIPT II.5. The latter two have been redesigned to capture the strengths of the microcomputer and mitigate its shortcomings. The four packages are all essentially portable to the mainframe in the sense that models developed on microcomputer will run with mainframe versions of the packages. (ARTHUR et al (64))

SIMSCRIPT II.5 is a very flexible and comprehensive system. It has a lot of capabilities in model building, incorporating statistical phenomena, input and output, analysis and graphics. SIMSCRIPT II.5 has many commands that makes it a programming language in which the programmer can develop any logic in the system to enhance the reality of the modeling. Three books are available for understanding the system and model building. (CACI (65), (66) AND (67)).

SKDMOD simulation model is developed under SIMSCRIPT II.5 language on the PC version. The language is flexible and capable of incorporating the operational phenomena but it requires a long time to train and master the package capabilities. A prototype model demonstrating airport passengers check-in using SIMSCRIPT II.5 and which helps understanding model building is studied and discussed with CACI.(CACI (68)).

6.3 **SKDMOD Model Building:**

SKDMOD is developed using PC SIMSCRIPT II.5 Simulation Language. This section will focus on the sub-models involved in SKDMOD and the logic diagram of the model.

6.3.1) **Disturbance Model:**

The disturbance model is one of the sub-models in SKDMOD. Based on the aircraft schedule plan and airline system resources this model generates random *delays* according to delay rates based on historical delay time distribution functions. Delay rate (DR_{sys}) is defined as the

number of delays expected for 100 departures on the entire system.

The purpose of this model is to *generate disturbances in the form of short / long delays to flights in the schedule*. The delay is called **original delay** which is applicable in the departure delay only.

A selection of disturbed flight is generated based on the historical delay data analysis in Chapter 3 where it was shown that 15% of the schedule flights were disturbed.

In the disturbance model, a random number is generated from a *uniform distribution function from (0,1)*. If the number is > 0.85 then the flight will have delay else the flight is not disturbed. In the case of a disturbance, the delay time is determined from the *lognormal function with mean and standard deviation as estimated in Chapter 4*. This delay time is called original delay time as appears in **figure (6-2)** and it is implemented in the flight schedule to simulate such delays and determine the propagation of the disturbances in future flights.

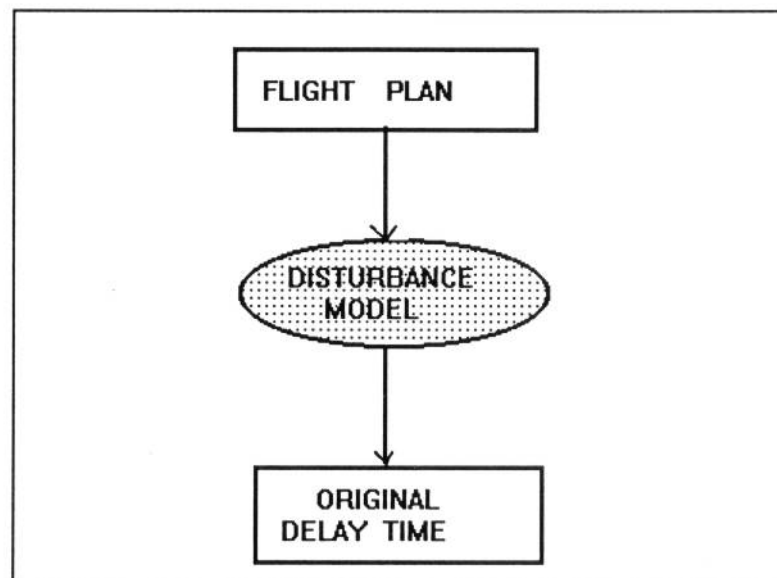


Figure (6-2) Disturbance Model

6.3.2) Recovery Model:

The delays in schedule (aircraft cycles) are combined with system resources and aircraft rotation plans in order to show how much that can reduce or eliminate the delays. This model is the most complex model in the Punctuality Management system. In practice, operational planners coordinate with marketing regarding deviation of another aircraft without affecting the departure of the flight which originally has been assigned to

this aircraft. Other actions might be the deviation of spare aircraft in case of serious technical problems. In other words airline operational complex decisions rules were simplified in this case for the simulation.

In this model the propagated delays are determined by simulation of the corrective actions taken by operations and marketing on the schedule which was subject to disturbances.

The input to recovery model is airline resources i.e. active and spare aircraft, schedule plans with different ground times, flights with original delays and delay times. After the *simulation of aircraft schedule plan* considering the model input and planners action, total delay time is determined. The output variable from this model is the total delay time called reactionary delay time, the change in the schedule and the measurement of the change to airline resources.

The recovery Model is the major sub-model in SKDMOD in which original delays are input into the flight schedule plan and simulated to determine the reactionary delays. Two processes were developed in this model; first **aircraft assignment process** and the **schedule process**. **Figure (6-3)** shows the link between the two processes and it will be discussed in more detail in the following sections. A/C is abbreviated for Aircraft and GT for Ground Time.

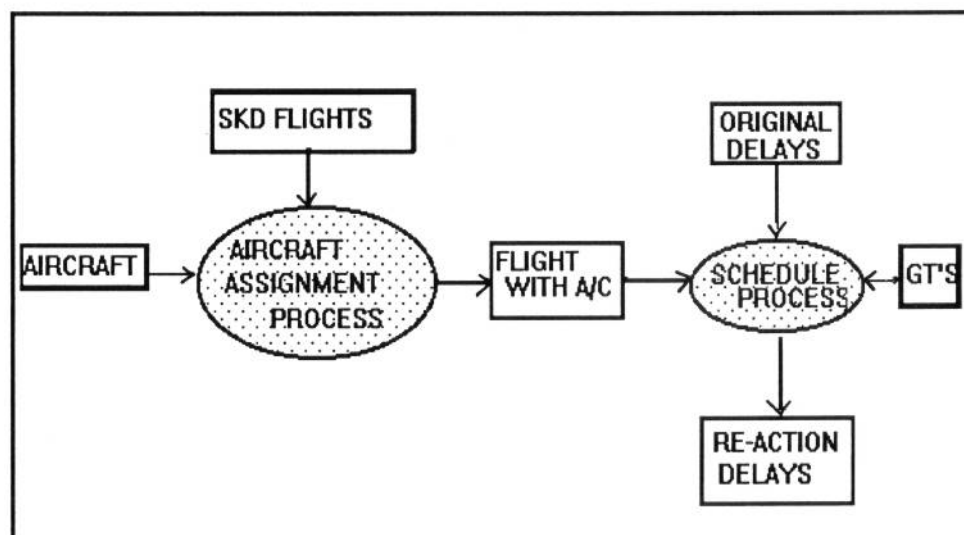


Figure (6-3) Recovery Model

a) **AIRCRAFT ASSIGNMENT PROCESS:**

The objective of this process is to assign an aircraft to the planned flight according to the schedule information which includes flight and aircraft type and ID. In practice, sometimes the planned aircraft is delayed in another station and the flight's

departure time is due, then another aircraft is diverted from the fleet or a spare aircraft is assigned to that flight and the spare aircraft will take over the rest of that aircraft cycle. The status of the spare aircraft becomes active and the delayed aircraft becomes spare after a period of time which corresponds to the maintenance period. It can then be assigned as a spare aircraft for future use.

This process is named as "ASSIGN.AC.TO.FLIGHT" in the SKDMOD coding, it uses aircraft and scheduled flights as input for the process then aircraft to flight assignment is the output of this process.

b) **SCHEDULE PROCESS:**

The objective of this process is to simulate the assigned flight and the assigned aircraft found from aircraft assignment process with other SKDMOD parameters such as ground time and original delays. The following are some of the major functions of this process;

Waiting for the flight scheduled departure time until it is due, accumulation of reactionary delay if it exists from previous trips, generation of disturbances (15% of the flight will be disturbed according to the delay analysis in chapter 3), and generation of original delay time using lognormal distribution function with mean, variance and random generator. During this process the original delay and the flight block time are simulated to determine the actual departure and arrival times. It also simulates the ground time. Minimum ground time is used for the delayed flights and maximum ground time is used for the on time arrival. When using the minimum ground time, the slack in the ground time will compensate for the delay. Minimum ground time equals the *main ground time* in which the necessary maintenance operations should be done and *slack time* on ground time is a buffer to be utilized when delays occurred. Maximum ground time equal to minimum ground time plus the slack time.

The main output of this process is the **reactionary and total delays**.

The recovery model uses parameters such as scheduled ground time, original delay, flight and aircraft assigned in aircraft assignment to determine the reactionary delays inherent in the schedule and spare

aircraft used for this level of punctuality.

6.3.3 SKDMOD LOGIC DIAGRAM:

Figure (6-4) describes the logic used in the SKDMOD simulation model. The logic starts with actual departure time of the flight equal to the scheduled departure time. Current time is used for the simulation clock purpose. Then a loop starts:

Aircraft assignment process is activated to check the availability of the scheduled aircraft, if aircraft is available then SKDMOD activates the schedule process to perform the following operations; calculate reactionary delays, wait original delays as assigned in "SCHEDULE PROCESS", determine total delays, wait for flight block time then calculate actual arrival.

The aircraft assignment process continues checking the availability of the aircraft every '5' minutes, for those aircraft which are not available, and accumulates the arrival delay time. There is a limit for aircraft arrival delay, this limit is set by the airline management to enable the operations to assign a spare aircraft instead. This limit is called in SKDMOD the maximum delay to assign a spare aircraft "MDAS". For delays longer than MDAS, SKDMOD will replace planned aircraft with a spare one and change the rest of the cycle with the new aircraft. The defect aircraft is under maintenance for a fixed time then the status of the aircraft will be changed to a spare after completion of the maintenance period. Then SKDMOD performs all the operations; calculate reactionary delays, wait original delays as assigned in "SCHEDULE PROCESS", determine total delays, wait for flight block time then calculate actual arrival.

As explained earlier scheduled ground time has two components, the first is a **minimum ground time** which is assigned for performing the required ground operations and the second component is a **slack time** for ground time which can be used in case of delays.

If a flight has an arrival delay then aircraft will wait for the minimum ground time only, and if the flight arrives on time then aircraft will wait for the scheduled ground time which includes both minimum ground time and the slack time. Then SKDMOD, in both cases, updates flight and aircraft information including actual departure and actual arrival. Then aircraft is released from its current engagement with this flight to get ready to assign to the next scheduled flight. After completion remove this flight from the schedule process.

SKDMOD will repeat the whole process for all the flights within aircraft cycles until all have been simulated. Then produce output reports; flight details report, aircraft report and daily performance report. At the end of the simulation period it produces a summary schedule performance report.

Figure (6-4) SKDMOD LOGIC DIAGRAM

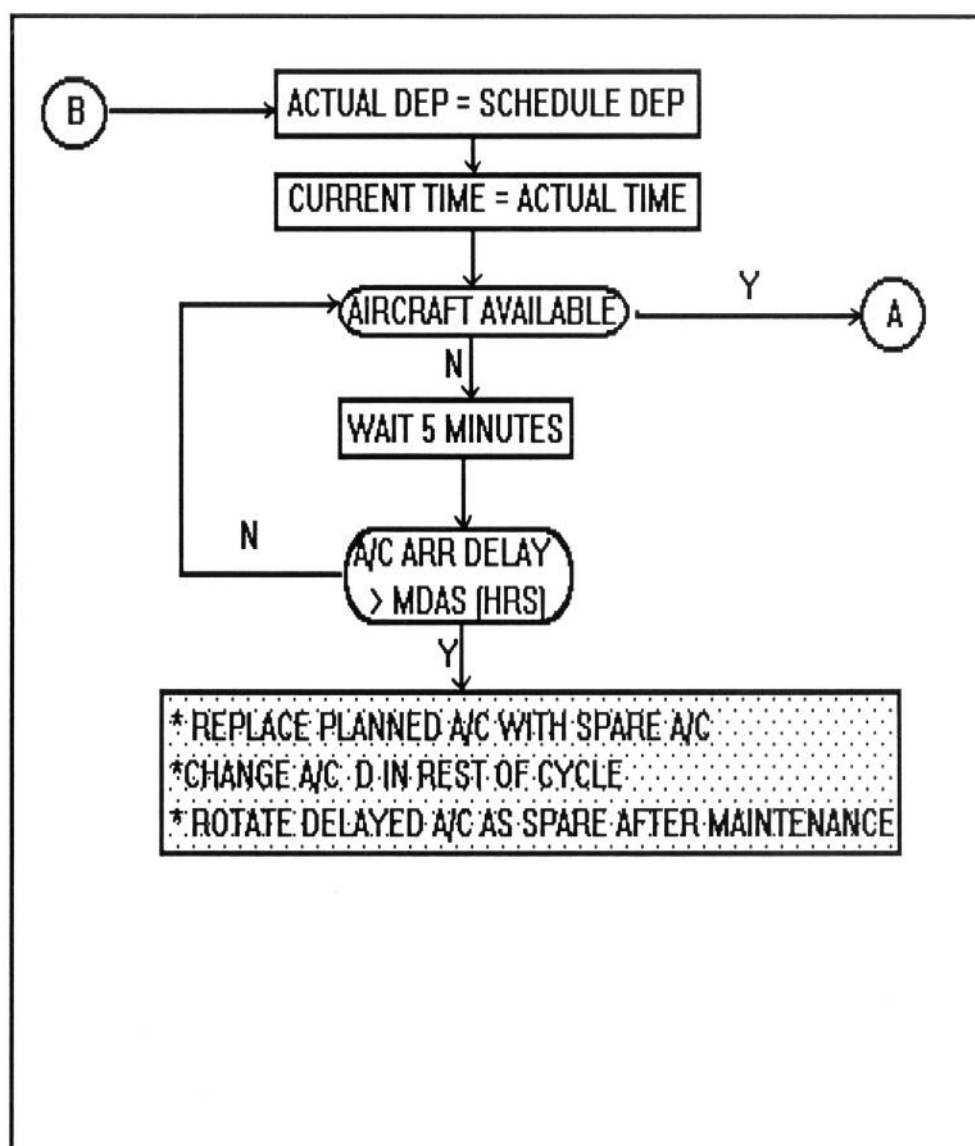
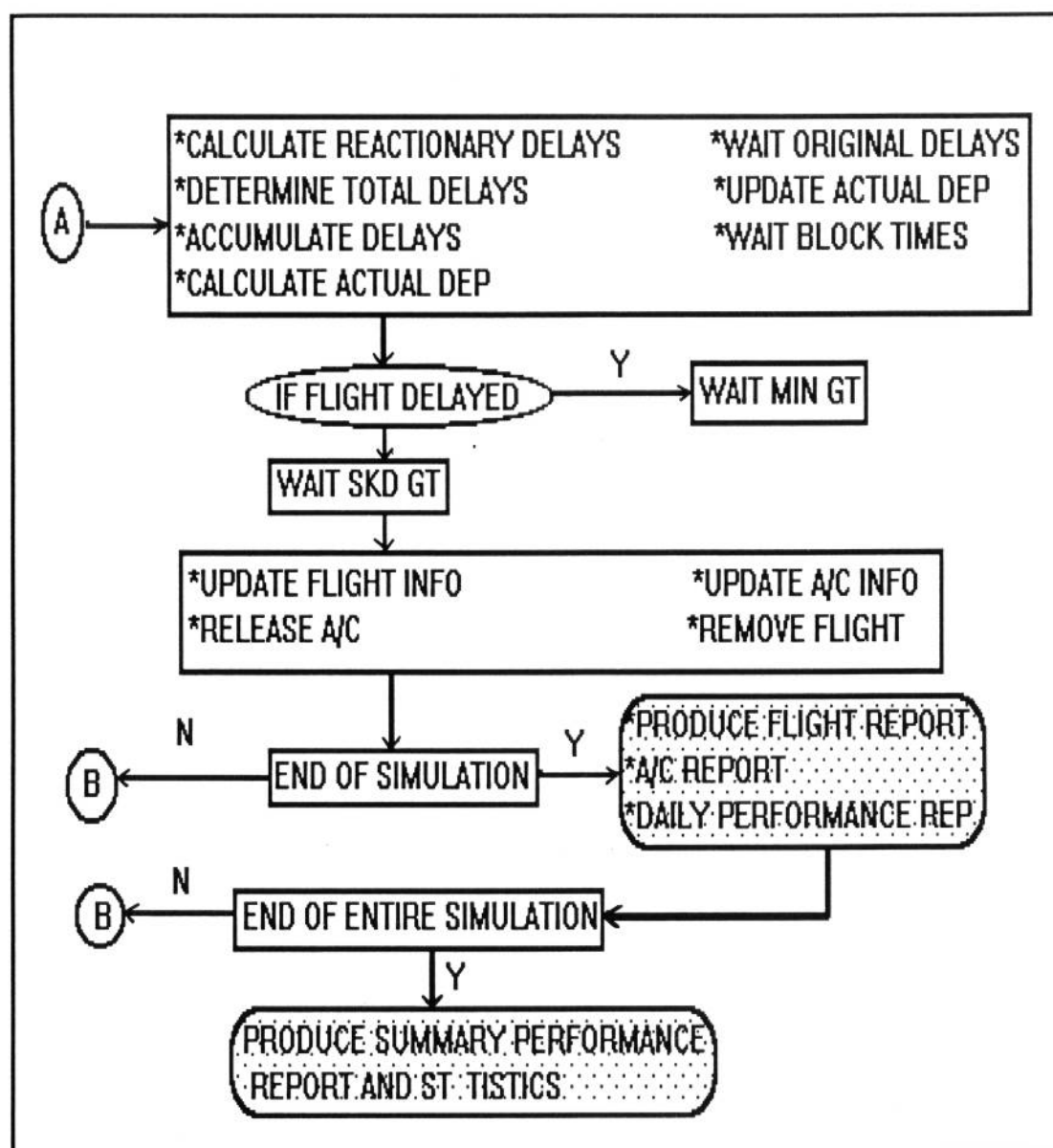


Figure (6-4) SKDMOD LOGIC DIAGRAM (Cont.)



6.4 SKDMOD Development:

In this section, a brief summary of the SKDMOD development including programming, the assumptions used when developing of the model, program structure and the SKDMOD flow diagram. The objective of this section is to shed light on the programming side of the model and some concepts of PC Simscript II.5. First the scope of the model is discussed.

6.4.1 SKDMOD Scope:

SKDMOD has few assumptions used when developing the model for the purpose of managing the scope and complexity of the model and the time limit. As mentioned earlier this model is a demonstration of the logic and the application of such model for punctuality management and optimization.

- a) Aircraft - SKDMOD simulates unlimited number of aircraft and cycles for **one** aircraft type.
- b) Spare Aircraft - SKDMOD assigns spare aircraft if arrival delay exceeds the maximum delay to assign spare which is represented in SKDMOD as MDAS. The value of MDAS is a corporate policy controlled by Airline Management. MDAS can interactively be updated and simulated directly from SKDMOD main menu without changing the programs.
- c) Aircraft Assignment - The Aircraft assignment logic in SKDMOD is constructed based on the planned aircraft cycle. Unless a long delay exceeds MDAS then a spare Aircraft will be assigned instead and the rest of the flights in the cycle changed.
- d) Disturbances - Delays which are used in SKDMOD are the only form of disturbances. Cancellation is the second form of disturbance which is found in the delay analysis. But for simplicity and to keep the model to a manageable size, cancellation is considered as a long delay especially as the percentage of the cancellation was small.
- e) Hubs / Network - SKDMOD simulates any number of flights or aircraft cycles operating in one hub network. Flights of multiple hubs can be used but all hubs will be considered as a normal stations except one hub which will be considered as the network hub.

6.4.2 SKDMOD Program Structure:

SKDMOD has 10 sub-programs; *A Preamble* in which all model declarations take place, *main program*, *set defaults routine*, *initialize routine*, *menu routine*, *trigger assignment routine*, *flight report routine*, *performance report routine*, *aircraft assignment process and schedule process* (CACI (65,66,67)). The following are more details of these programs.

- 1) **PREAMBLE** - In Simscript II.5 any model starts with this program which contains all **declarations** for all entities and attributes associated with these entities. Declarations of processes included in the model and attributes of these processes. Declarations of other system variables and sets.(CACI (65)).

Declaration of output variables used for statistics in the output reports. Preamble also contains the "Tally" command which is used in SKDMOD to determine statistics of original delays, reactionary delays and total delays. Total delay statistics are divided into two forms the first include any delay and the second include any delay which is greater than 15 minutes.

In the preamble all declarations are considered for permanent entities, aircraft/flight attributes and system/global variables. Permanent Entities such as flight and aircraft, flight attributes such as flight ID (fl.id), flight schedule departure (fl.skd.dep), flight schedule arrival (fl.skd.arr), flight actual departure (fl.act.dep) etc. Aircraft attributes such as aircraft ID (ac.id), aircraft status (ac.status), aircraft location (ac.location) etc. Global/System variables such as mean delay time for the delay distribution function (mean.del.time), ground time (ground.time), end time for total simulation (end.time). Sets are used such as flight queue (fl.queue), flight list (fl.list), aircraft list (ac.list) etc. All declarations are shown in the list of the program in Appendix d.

- 2) **Main** - main program contains call statements for SKDMOD routines.
- 3) **Set default routine** - initial the SKDMOD variables with defaults that can be updated in MENU routine.
- 4) **MENU Routine** - The program that runs the SKDMOD menu with default values then options of update these values or run/stop simulation. In menu program, limits on these variables were built in to edit unrealistic changes.

- 5) **Initialize Routine** - Initialize routine reads and saves flight and aircraft from flight data file and aircraft data file respectively. Then flight entities are filed in flight queue set and aircraft entities are filed in aircraft list.
- 6) **Trigger assignment routine** - This routine will activate the aircraft assignment process in 'flight holding time' which equals the difference between flight scheduled departure time and current time.
- 7) **Flight Report Routine** - For every flight in the flight queue after simulation a detailed information of the flight schedule and actual status are generated. Information contains origin, destination, flight, block time, aircraft planned, schedule departure, schedule arrival, aircraft actual, actual departure, actual arrival, flight original delays, reactionary delays, and total delays.
- 8) **Performance Report** - The performance report is produced at the completion of simulation run. It contains statistics on operations and punctuality. Information generated includes, active and spare fleet, total departures, total block times, mean and standard deviation of log normal delay function, total delays and total delay times for all delays > 0 minutes and delay > 15 minutes. Details of original and reactionary delays, min, max and average delay time are also presented. In the program all delays > 0 minute were designated by all delay variables and all delays > 15 minutes were called serious delays.
- 9) **Aircraft Assignment Process** - In SKDMOD this process is called assign aircraft to flight "assign. ac.to.flight".

In this process, flight will be assigned to the planned aircraft in case of zero or minimal delays. If delays were long and exceed maximum delay time for assignment spare aircraft (MDAS) then a spare aircraft will be assigned and aircraft status will be exchanged. Delayed aircraft will be spare and spare will take over rest of the cycles. The output of this process is assigned flight and assigned aircraft.

- 10) **Schedule Process** - The schedule process will simulate flight and assigned aircraft to determine the reactionary delays resulting from late aircraft arrival or delay in aircraft assignment in aircraft assignment process. Actual departure time will be updated according to original delays resulting from disturbance model. It is simulated with block time to determine the actual arrival. Ground times are classified into two parts. Minimum ground time

in which aircraft should require this period of time for necessary maintenance. The difference between scheduled ground time and minimum ground time equals slack time used as a buffer to be used in case of disturbances. If flight is delayed the model will use minimum ground time and utilize the slack time for recovery and if not the model will use scheduled ground time.

SKDMOD has about **900 lines of Simscript II.5** coding appears in Appendix (D).

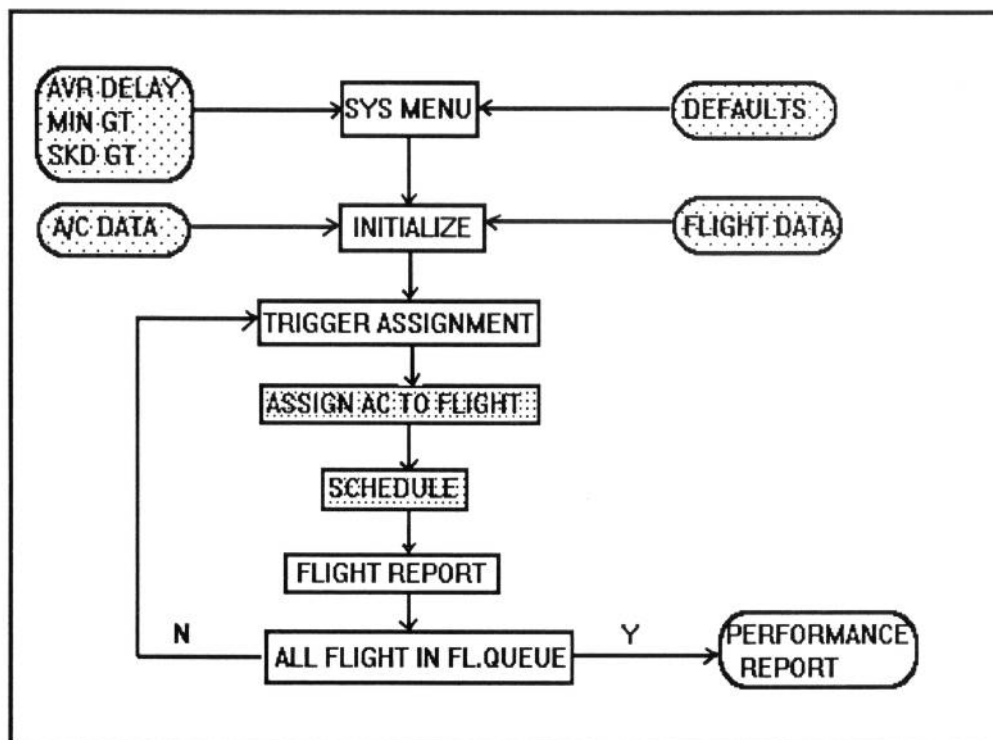
6.4.3 **SKDMOD Flow Diagram:**

The diagram appears in **figure (6-5)** explains the SKDMOD flow diagram between routines and process. In the model main menu, there are options to change the default values for ground times, mean delay time of the log normal distribution function and end of simulation time. The second step is to initialize aircraft and flight entities within the 'initialize routine' as appears in figure (6-5). This routine will read aircraft data and flight data. Then flight entities and aircraft entities are saved in sets i.e. flight queue and aircraft list respectively.

Based on flight schedule departure time trigger assignment routine for aircraft assignment "assign.ac.to.flight" will assign planned or spare aircraft to flights according to the logic discussed in the previous section. With the assigned aircraft and assigned flight, SKDMOD simulates schedule with original delays generated from disturbance model to determine the reactionary delays and determine the actual departure and arrival of flights. Then the flight report is produced for each flight in the flight queue.

Then SKDMOD checks if all flights in flight queue is simulated, if yes then output performance report are generated, if no SKDMOD will continue simulating all rest of flights. Output reports are produced at the end of simulation including delays statistics and punctuality performance for all delays and for the serious delays.

Figure (6-5)

SKDMOD FLOW DIAGRAM

6.5 SKDMOD Input:

To run SKDMOD, some input data are required. Some of these data can be input interactively when running the model and some input data are saved in data files and some are hard coded in the SKDMOD programs. The following are the major input data used in the model:

- 1) **Schedule Plan** - Details of flights in the schedule plan which contains; aircraft, origin, destination, scheduled departure, scheduled arrival, flight id and flight block time. All flights details stored in an external file called "Flight.dat" available in the same directory of the model. For the analysis purposes it is possible to have a number of these files containing different plans. **Figure (6-6)** shows a sample of one of the flight data files used by this model i.e aircraft AA flying from RUH to ELQ departure time is 0245, arrival time is 0340, flight number is 781 and block time is 55 minutes (first digit is used for hours and next two digits are used for minutes).


```

AA 1 RUH ELQ 0245 0340 781 055
AA 2 ELQ RUH 0430 0515 782 045
AA 3 RUH EAM 0705 0840 975 135
AA 4 EAM RUH 0930 1055 974 125
AA 5 RUH YNB 1150 1345 861 155
AA 6 YNB RUH 1435 1600 860 125
AA 7 RUH ELQ 1715 1800 793 045
AA 8 ELQ RUH 1900 1945 794 045
BB 1 JED AHB 0325 0425 888 100
BB 2 AHB RUH 0515 0640 952 125
BB 3 RUH HOF 0720 0810 104 050
BB 4 HOF RUH 0855 0940 105 045
BB 5 RUH BHH 1050 1215 979 125
BB 6 BHH RUH 1305 1415 980 110
BB 7 RUH GIZ 1520 1710 963 150
BB 8 GIZ RUH 1800 1935 962 135
CC 1 RUH MED 0250 0420 795 130
CC 2 MED RUH 0515 0630 796 115
CC 3 RUH DHA 0710 0810 102 100
CC 4 DHA RUH 0920 1020 103 100
CC 5 RUH DHA 1100 1200 484 100
CC 6 DHA RUH 1330 1430 483 100
CC 7 RUH HAS 1605 1715 839 110
CC 8 HAS RUH 1810 1915 840 105
DD 1 RUH TUU 0300 0450 807 150
DD 2 TUU RUH 0545 0725 808 140
DD 3 RUH ELQ 1030 1125 835 055
DD 4 ELQ RAH 1155 1250 835 055
DD 5 RAH ELQ 1345 1445 834 100
DD 6 ELQ RUH 1515 1600 834 045
DD 7 RUH EAM 1705 1840 977 135
DD 8 EAM RUH 1930 2055 976 125
EE 1 JED EJH 0420 0525 822 105

```

Figure (6-6) Sample of flight data

- 2) **Aircraft Data** - Details about active and spare aircraft involves; aircraft id, aircraft location, aircraft code and aircraft status. All aircraft data is stored in "Aircraft.dat" file. **Figure (6-7)** illustrates a sample of aircraft data file used by SKDMOD model i.e. aircraft AA located in RUH, status is ACTIVE. NOT ASSIGNED and ALLOWED are used internally by the model.

```

AA RUH ACTIVE NOT.ASSIGNED ALLOWED
BB JED ACTIVE NOT.ASSIGNED ALLOWED
CC RUH ACTIVE NOT.ASSIGNED ALLOWED
DD RUH ACTIVE NOT.ASSIGNED ALLOWED
EE JED ACTIVE NOT.ASSIGNED ALLOWED
FF RUH ACTIVE NOT.ASSIGNED ALLOWED
GG JED ACTIVE NOT.ASSIGNED ALLOWED
SA RUH SPARE NOT.ASSIGNED ALLOWED
SB RUH SPARE NOT.ASSIGNED ALLOWED

```

Figure (6-7) Sample of Aircraft data

- 3) **Ground Times** - Minimum ground times and slack times used as buffers are set by default which is initialized by the 'default routine' in SKDMOD. But from SKDMOD main menu ground times can be updated interactively to determine the effect of low or high ground times on Simulation results.
- 4) **Maximum Delay to Assign Spare Aircraft (MDAS)** - MDAS represents management strategy to determine the effect on schedule punctuality. MDAS is updated interactively from SKDMOD main menu.

6.6 SKDMOD Output Reports:

SKDMOD produces **four** output reports. The daily report shows details of the every flight performance in the schedule called ***Flight Report***, the second report show statistics on the schedule performance for that day, called ***Daily Schedule Performance Report***. The third report illustrates the utilization of each aircraft in the active and spare fleet, called ***Aircraft Utilization Report***. The fourth report gives ***summary statistics*** of all simulation days for the entire schedule.

- 1) **Fight Report** - After simulating each flight, the flight report will be activated. Details about the planned and actual status of the flight is shown.

The flight report shows details about origin, destination, flight number, block time, schedule aircraft, schedule departure and schedule arrival. Actual aircraft assigned, actual departure and actual arrival time. The flight delays statistics on original delay, reactionary delay and total delays. **Figure (6-8)** shows a sample of flight report for a set of input values. Flight number 781 from RUH to ELQ scheduled for departure on 0245 and arrival on 0340 hours. It happens that this flight has an original delay of 35 minutes so the actual departure time becomes 0320 and actual arrival time becomes 0415 hours. The next flight in the cycle for aircraft AA is flight number 782 from ELQ to RUH, scheduled for departure on 0430 and scheduled for arrival on 0515, but the actual arrived to ELQ is 35 minutes later. The scheduled ground time is 50 minutes for this simulation report. As discussed in the schedule process of SKDMOD if a flight has a delay then the minimum ground time is considered instead of the scheduled ground time. This will reduce the reactionary delay and the propagation on the next flight. So aircraft AA will stay 30 minutes as the minimum ground time and flight number 782 will depart on 0450 instead of 0430 hours. So flight number 782 has 20 minutes delay as a reactionary delay instead of 30 minutes. The next flight for AA is flight number 975 from RUH to EAM, scheduled for

departure on 0705 and scheduled for arrival on 0840 hours. This flight is on time and the effect of delays is recovered because AA have enough ground time in RUH before the next flight.

Another example where aircraft have a disturbance in the middle of its cycle. Aircraft CC has two flights on time, flight numbers 795 and 796. But flight number 102 has an original delay of 1 hour and 2 minutes which affect the next flight, flight number 103. This flight has a reactionary delay of 25 minutes and an original delay of 24 minutes so the total delay for flight number 103 is 49 minutes. The cycle continues where flight number 484 has a 40 minutes delay as a reactionary delay from the previous delays. Next flight on aircraft CC cycle is on time.

Aircraft BB shows an example of using a spare aircraft in the cycle. The first flight is on time (flight number 888) but the second flight has an original delay of 1 hour and 50 minutes (flight number 952). The MDAS value in this simulation report is 1 hour. Flight number 952 has a delay more than the MDAS value but the aircraft is not diverted. This is true because this delay exists in AHB and all our spare aircraft are based in RUH. It will take longer to get the spare aircraft to AHB. According to SKDMOD assumptions that all spare aircraft stay at the hub station (RUH). The next flight in BB cycle is flight number 104 which has 1 hour reactionary delay. SKDMOD diverts aircraft BB and replaces it with a spare aircraft SA because the flight departs from RUH. This will reduce reactionary delays for the rest of the SA cycle. Aircraft BB will be staying in the spare fleet after maintenance. The maintenance period is assumed to be two hours for the demonstration purposes.

So SKDMOD flight report is the most detailed report SKDMOD produces which shows the effect of the management strategies that are used in the simulation model such as slack times in the ground time and diversion to spare aircraft.

Figure (6-8) Sample of Flight Report

		FLT BLK	--SKEDULE--		--ACTUAL--		--DELAYS----					
ORG	DST	NUM	TIME	AC	DEP	ARR	AC	DEP	ARR	ORG	REACT	ALL
RUH	ELQ	781	55	AA	245	340	AA	320	415	35	0	35
RUH	MED	795	130	CC	250	420	CC	250	420	0	0	0
JED	AHB	888	100	BB	325	425	BB	325	425	0	0	0
RUH	GIZ	961	150	FF	305	455	FF	305	455	0	0	0
JED	EJH	822	105	EE	420	525	EE	420	525	0	0	0
RUH	TUU	807	150	DD	300	450	DD	340	530	40	0	40
ELQ	RUH	782	45	AA	430	515	AA	450	535	0	20	20
JED	HAS	762	115	GG	445	600	GG	445	600	0	0	0
MED	RUH	796	115	CC	515	630	CC	515	630	0	0	0
EJH	TUU	822	50	EE	550	640	EE	555	645	0	5	5
HAS	AJF	762	45	GG	630	715	GG	630	715	0	0	0
GIZ	RUH	960	135	FF	545	720	FF	545	720	0	0	0
TUU	RUH	808	140	DD	545	725	DD	605	745	0	20	20
AHB	RUH	952	125	BB	515	640	BB	705	830	150	0	150
TUU	URY	822	50	EE	740	830	EE	740	830	0	0	0
RUH	EAM	975	135	AA	705	840	AA	705	840	0	0	0
RUH	ELQ	106	55	FF	755	850	FF	755	850	0	0	0
AJF	HAS	763	45	GG	815	900	GG	815	900	0	0	0
RUH	HOF	104	50	BB	720	810	SA	820	910	0	100	100
RUH	DHA	102	100	CC	710	810	CC	812	912	102	0	102
HOF	RUH	105	45	SA	855	940	SA	940	1025	0	45	45
URY	RUH	822	145	EE	900	1045	EE	905	1050	0	5	5
EAM	RUH	974	125	AA	930	1055	AA	930	1055	0	0	0
DHA	RUH	103	100	CC	920	1020	CC	1009	1109	24	25	49
RUH	ELQ	835	55	DD	1030	1125	DD	1030	1125	0	0	0
ELQ	RUH	107	55	FF	1030	1125	FF	1104	1159	34	0	34
RUH	BHH	979	125	SA	1050	1215	SA	1100	1225	0	10	10
RUH	AQI	817	55	EE	1145	1240	EE	1145	1240	0	0	0
RUH	DHA	484	100	CC	1100	1200	CC	1140	1240	0	40	40
ELQ	RAH	835	55	DD	1155	1250	DD	1155	1250	0	0	0
HAS	JED	763	120	GG	935	1055	GG	1133	1253	158	0	158
RUH	HOF	984	50	FF	1205	1255	FF	1230	1320	0	25	25
RUH	YNB	861	155	AA	1150	1345	AA	1150	1345	0	0	0
AQI	RUH	818	45	EE	1330	1415	EE	1330	1415	0	0	0
BHH	RUH	980	110	SA	1305	1415	SA	1305	1415	0	0	0
DHA	RUH	483	100	CC	1330	1430	CC	1330	1430	0	0	0
HOF	RUH	985	45	FF	1345	1430	FF	1350	1435	0	5	5
JED	MED	714	50	GG	1345	1435	GG	1345	1435	0	0	0
RAH	ELQ	834	100	DD	1345	1445	DD	1345	1445	0	0	0
RUH	HOF	109	35	EE	1450	1525	EE	1450	1525	0	0	0
YNB	RUH	860	125	AA	1435	1600	AA	1435	1600	0	0	0
MED	JED	715	50	GG	1525	1615	GG	1525	1615	0	0	0
ELQ	RUH	834	45	DD	1515	1600	DD	1540	1625	20	5	25
HOF	RUH	101	45	EE	1605	1650	EE	1605	1650	0	0	0
RUH	GIZ	963	150	SA	1520	1710	SA	1520	1710	0	0	0
RUH	HAS	839	110	CC	1605	1715	CC	1605	1715	0	0	0
RUH	ELQ	793	45	AA	1715	1800	AA	1715	1800	0	0	0
RUH	RAE	847	145	FF	1650	1835	FF	1650	1835	0	0	0
JED	AHB	598	100	GG	1740	1840	GG	1740	1840	0	0	0
RUH	EAM	977	135	DD	1705	1840	DD	1705	1840	0	0	0
HAS	RUH	840	105	CC	1810	1915	CC	1810	1915	0	0	0

- 2) **Daily Performance Report** - A summary report after running all simulations with aggregates on operating statistics; active fleet, total departure and block hours. Delay distribution function mean and standard deviation. Punctuality stats for all delays >0 minutes and >15 minutes includes total delays, original delays, reactionary delays, total delays, minimum, maximum, average delay time then punctuality

performance percentage. Figure (6-9) shows a sample of this report.

DAILY PERFORMANCE SUMMARY REPORT		
A) OPERATING STATS :		
FLEET	= 9	AIRCRAFT
TOTAL DEPARTURES	= 56	FLIGHTS
TOTAL BLK HRS	= 64.08	HOURS
B) DELAY FUNCTION PARAMETERS :		
MEAN DELAY TIME	= 1.0000	HOURS
STANDARD DEV	= 1.0724	HOURS
C) PUNCTUALITY STATS FOR ALL DELAYS (> 0 min) :		
TOTAL DELAYS	= 19	DELAYS
TOTAL DELAY TIME :		
ORIGINAL DELAYS	= 8.35	HOURS
REACTION DELAYS	= 4.42	HOURS
ALL DELAYS	= 12.77	HOURS
MIN DELAY TIME	= .08	HOURS
MAX DELAY TIME	= 1.96	HOURS
AVR DELAY TIME	= .67	HOURS
PUNCTUALITY PERFORMANCE (> 0 min) = 66.07 %		
D) PUNCTUALITY STATS FOR ALL DELAYS (> 15 mins) :		
TOTAL DELAYS	= 15	DELAYS
TOTAL DELAY TIMES	= 12.35	HOURS
MIN DELAY TIME	= .33	HOURS
MAX DELAY TIME	= 1.96	HOURS
AVR DELAY TIME	= .82	HOURS
PUNCTUALITY PERFORMANCE (> 15 mins) = 73.21 %		

Figure (6-9) Sample of Daily Performance Report

- 3) **Aircraft Utilization Report** - A summary operating report shows the aircraft id, daily utilization of aircraft in hours, the status of the aircraft at the end of that day. **Figure (6-10)** shows seven active aircraft and two spares are used in one of the simulation exercises. At that day aircraft BB became a spare and the spare aircraft SA took the BB cycle as appears from the results.

AA	9.50	hrs	ACTIVE
BB	2.42	hrs	SPARE
CC	9.00	hrs	ACTIVE
DD	10.08	hrs	ACTIVE
EE	7.50	hrs	ACTIVE
FF	10.25	hrs	ACTIVE
GG	7.75	hrs	ACTIVE
SA	7.58	hrs	ACTIVE
SB	0.	hrs	SPARE

Figure (6-10) Sample of Aircraft Utilization

- 4) **Schedule Performance Report** - At the end of the simulation period i.e. 200 days in this case, **figure (6-11)** illustrates the summary results including operating statistics, delay function parameters used in the disturbance model, results of punctuality analysis for all delays more than 0 minutes and all delays more than 15 minutes and summary of parameters used and statistics produced from SKDMOD.

SCHEDULE PERFORMANCE SUMMARY REPORT

A) OPERATING STATS :

FLEET	= 9	AIRCRAFT
TOTAL DEPARTURES	=11200	FLIGHTS
TOTAL BLK HRS	=12816.67	HOURS

B) DELAY FUNCTION PARAMETERS :

MEAN DELAY TIME	= 1.0000	HOURS
STANDARD DEV	= 1.0724	HOURS

C) PUNCTUALITY STATS FOR ALL DELAYS (> 0 min) :

TOTAL DELAYS	= 3633	DELAYS
TOTAL DELAY TIME :		
ORIGINAL DELAYS	=1686.04	HOURS
REACTION DELAYS	=1552.33	HOURS
ALL DELAYS	=3212.07	HOURS
MIN DELAY TIME	= .05	HOURS
MAX DELAY TIME	= 16.30	HOURS
AVR DELAY TIME	= .88	HOURS

PUNCTUALITY PERFORMANCE (> 0 min) = 67.56 %

D) PUNCTUALITY STATS FOR ALL DELAYS (> 15 mins) :

TOTAL DELAYS	= 2748	DELAYS
TOTAL DELAY TIMES	=3104.56	HOURS
MIN DELAY TIME	= .25	HOURS
MAX DELAY TIME	= 16.30	HOURS
AVR DELAY TIME	= 1.13	HOURS

PUNCTUALITY PERFORMANCE (> 15 mins) = 75.46 %

E) SKDMOD SUMMARY :

M D A S	= 1.00	HOURS
PLAN GROUND TIME (SKD)	= 30.00	MINS
SIMULATION PERIOD	= 200	DAYS
AVR DELAY TIME / DAY :		
ALL DELAYS	= 16.06	HOURS
SERIOUS DELAYS	= 15.52	HOURS

Figure (6-11) Sample of Schedule Performance Report

6.7 Application of SKDMOD:

SKDMOD is used to simulate part of Saudia B737 domestic schedule as a sample from which SKDMOD can demonstrate the capabilities of the model especially when simulating different management strategies. Cycles of B737 are the most crowded and B737 aircraft tend to service domestic and regional markets. Seven aircraft cycles with about 60 flights and 2 spare aircraft is the application dimensions. Based on these values many strategies were simulated and analyzed further in chapter (7) and chapter (8).

SKDMOD runs on IBM PC/AT with 80287 Math Co-Processor because that is the SIMSCRIPT II.5 requirement. After invoking SIMLAB in SIMSCRIPT II.5. SKDMOD can run using RUN command and the default menu will appear. **Figure (6-12)** illustrates the main menu with some of the input data.

The defaults can be changed through the options existing in SKDMOD such as Mean delay time which is used in the Log normal delay distribution function, minimum ground time, scheduled ground time, length of simulation time.

At the bottom of the menu there are options to run simulation or exit from simulation. If run is used then the output reports are produced including flight report and performance report.

Schedule Simulation Menu

Default values

Mean Delay Time	=	**,***	Hours
Min Ground Time	=	***.*	Minutes
Pln Ground Time	=	***.*	Minutes
M D A S Time	=	**,*	Hours
Simulation Time	=	***	Day(s)

- 1) Change the Mean Delay Time
- 2) Change the MIN Ground Time
- 3) Change the Planned Ground Time
- 4) Change the MDAS time
- 5) Change the Simulation Duration

R) Run the simulation
E) Exit the simulation

Figure (6-12)

SKDMOD Main Menu

CHAPTER (7)

RESULTS OF STRATEGIES SIMULATION

This chapter uses the SKDMOD simulation model discussed in chapter (6). The objective of this chapter is to simulate the airline management punctuality strategies in order to determine the airline schedule performance in terms of punctuality and strategies used. The impact of these strategies in terms of the economics of the operations is subject to detailed optimization formulation and analysis in chapter (8).

In this chapter the model will be applied using different values of the strategies i.e. slack times in ground time and spare aircraft etc. Section 7.1 reviews the airline strategies which were discussed earlier and section 7.2 explains the strategies which are developed and applied in the SKDMOD model. Section 7.3 illustrates the sets of strategies and the necessary input data. Section 7.4 discusses the output of simulating these strategies. Then the summary of results of strategies simulation is presented in the conclusion, section 7.5.

7.1 INTRODUCTION:

As previously discussed earlier punctuality can be managed better and the level of performance can be improved by adopting different strategies depending upon the severity of the schedule disturbances. These strategies can be categorized into three types of management strategies. *Planning strategies, operational strategies and supportive strategies*. The following are some of the possible strategies that management can practice and some of them are used in airlines but not only in the context of punctuality management:

- a) Providing more *slack time in flight duration*, to be considered as a buffer, is one of the planning strategies. The planned flight duration has both the expected block time plus the slack time. All scheduling activities are using the flight duration with the proposed slack time and it will be published in the airline timetable accordingly. Normally passengers do not notice it, but they will appreciate either arrival ahead of planned time if there are no delays or slightly late if there is a delay. On the other hand the airline suffers from low utilization of aircraft, cockpit and cabin crews and other ground facilities. This low utilization cannot be improved because aircraft, crews and other equipments are engaged and they are considered as active resources.

- b) Providing *slack time in the aircraft ground time* when the airline develops its schedule plans using the schedule ground time as it is called in chapter (6). The scheduled ground time has two components, one is the minimum ground time and the second is the slack ground time. The minimum ground time is the time which is required to complete all the necessarily ground functions. The slack ground time exists to cater for irregularity in the schedule.
- c) Providing facilities for easy *aircraft diversion* from the planned cycles into different ones is an example of the operational strategies. This strategy normally increases airline operational cost. In this case aircraft rotation plans are usually consulted to determine the flight operation feasibility of aircraft diversion of the same aircraft type or different configuration depends on the availability of the fleet at that time.
- d) Increasing *ground crews* in case of shortage or improving their professionalism qualifications by more target training and on the job training. Ground crews refer here to all marketing and technical staff working in airport ground aiming to serve aircraft. Traffic control, catering, general airport services are examples of marketing manpower exists in the airport. This strategy is an example of supportive strategies which affect punctuality.
- e) Provisioning of additional *spare aircraft* to the airline fleet which can be used when scheduled aircraft are unavailable.
- f) Improving the *preventive maintenance* procedure and ways to control its implementation.
- g) Implementing of normal staff and station performance *encouragement* by adopting different award policies and approaches, i.e. the best rated on time performance station in both domestic and international network or the best employee in the division, etc..

In any case, most of the previous mentioned strategies are subject to the management decision making. **These strategies have a trade off between adding more airline operational costs and possibilities of influencing passengers satisfaction which in turn may affect the passengers revenue.** In the following section only the strategies which are modeled in SKDMOD are discussed.

7.2 SKDMOD Schedule Strategies:

Some of the above mentioned strategies affect the airline operations directly and some indirectly. Providing slack times in aircraft ground time or/and providing slack times in flight block time as a buffer when schedule planning and number of spare aircraft used in the schedule are examples of the strategies which directly affect the airline operations and consequently the level of punctuality.

SKDMOD model simulates the following strategies and based on that this chapter provides an analysis of these strategies.

7.2.1 Slack Ground Time:

Provide a slack time in aircraft schedule ground time when actually developing the schedule plan. For any reason if a flight is delayed the provided slack time can be utilized to overcome this delay entirely or partially. For any flight, *scheduled ground time* equals the minimum ground time and the slack ground time which is provided for the punctuality purposes i.e aircraft 'B737' requires 30 minutes minimum ground time, the schedule planners assign 40 minutes instead. The extra 10 minutes in aircraft ground time is the slack ground time and it is stored as a buffer. In case of normal operating conditions, aircraft and cabin cockpit crews are occupied while actually they are waiting for the extra slack time. But in case of delay this slack time can be utilized to overcome this delay either partially or entirely.

In this simulation, **three different schedules** are used for the same sample network. These schedules have three different established ground times. Schedule #1 uses a 30 minutes schedule ground time, schedule #2 uses a 40 minutes scheduled ground time and schedule #3 uses a 50 minutes scheduled ground time. These scheduled ground times are selected to demonstrate the effect of changing the scheduled ground time including the slack ground time in the overall schedule punctuality.

7.2.2 Maximum Delay to Assign Spare Aircraft (MDAS):

Maximum delay time to assign a spare aircraft, abbreviated as (MDAS), is an operational strategy which can be adopted by management while the implementation process of the schedule plan. If a flight is delayed then a spare aircraft is assigned **only** if the delay time of this flight exceeded MDAS value.

For example, MDAS equals 2 hours for a specific schedule plan. While implementation of this schedule, a flight has a delay of 1.5 hours then the SKDMOD will not assign a spare aircraft to fly that flight but it will

wait and the flight delay time will be 1.5 hours. On the other hand, if another flight has a delay of three hours then the SKDMOD will assign a spare aircraft from the spare fleet when ever the accumulative delay time exceeds 2 hours. By using the MDAS strategy of 2 hours the flight total delay time is two hours and one hour delay time is reduced. Similarly, if MDAS equals one hour then a spare aircraft will be assigned after exceeding one hour flight delay time so a reduction of two hours delay time takes place by using this strategy.

In this simulation, a range of MDAS values are used with the three schedule plans. MDAS = 1, 2, 3, 4, 5 and 6 hours each used with each schedule plan.

7.2.3 Spare Aircraft:

The availability of spare aircraft is the third strategy that is considered in SKDMOD. As a result of adopting certain strategies the schedule might require nil or one or two spare aircraft. In this simulation model, a maximum number of spare aircraft are two which can be used by the system. The model can use any number of spare aircraft but knowing the size of the schedule plan that is used here will not require more than two with high utilization factor. A warning message appears when the schedule needs more than two spares.

7.3 Strategies Simulation:

For the purpose of demonstration the impact of the strategies considered above, three different schedule plans are developed. Each **schedule plan** simulated represents **one day cycles contains 65 flights** serving a sub network of Saudi Arabia with one type of fleet using different scheduled ground time 30, 40 and 50 minutes.

Different values for MDAS's are considered. Using the interactive menu of SKDMOD to simulate these strategies with six different values of MDAS's (1, 2, 3, 4, 5 and 6) hours. These values are selected to demonstrate the variation of MDAS's how much can affect the schedule punctuality and the number of spare aircraft and its utilization.

The following illustrates the contents of the sets of strategies and the corresponding input values.

a) Strategy Set # 1:

Schedule plan contains of 65 flights using a **fleet** of 9 aircraft including two spares. The **scheduled ground time (SGT)** is 30 minutes including zero slack ground time. **MDAS values** which are used in this simulation are 1, 2, 3, 4, 5 and 6 hours. So in strategy set # 1, there are six strategies with different MDAS values and same ground time as follows:

<u>Strategy#</u>	<u>SGT</u>	<u>MDAS</u>
1	30	1
2	30	2
3	30	3
4	30	4
5	30	5
6	30	6

b) Strategy Set # 2:

Schedule plan contains of 65 flights using a **fleet** of 10 aircraft including two spares. The **scheduled ground time (SGT)** is 40 minutes including 10 minutes slack ground time. **MDAS values** which are used in this simulation are 1, 2, 3, 4, 5 and 6 hours. So in strategy set # 2 There are six strategies with different MDAS values and same ground time as follows:

<u>Strategy#</u>	<u>SGT</u>	<u>MDAS</u>
7	40	1
8	40	2
9	40	3
10	40	4
11	40	5
12	40	6

c) Strategy Set # 3:

Schedule plan contains of 65 flights using a **fleet** of 11 aircraft including two spares. The **scheduled ground time** (SGT) is 50 minutes including 20 minutes slack ground time. **MDAS values** which are used in this simulation are 1, 2, 3, 4, 5 and 6 hours. So in strategy set # 3 There are six strategies with different MDAS values and same ground time as follows:

<u>Strategy#</u>	<u>SGT</u>	<u>MDAS</u>
13	50	1
14	50	2
15	50	3
16	50	4
17	50	5
18	50	6

In summary, **18 strategies** are simulated using SKDMOD simulation model. When running one strategy SKDMOD simulates the flight schedule with a delay function being inserted to determine the overall effect on schedule punctuality. Three different reports are produced; flight performance report, aircraft utilization report, daily performance report and schedule summary performance report as explained in chapter (6).

7.4 RESULTS:

Each strategy is simulated for **200 days**. SKDMOD takes on average **1.5 hours** to complete the strategy simulation upon completion of each day SKDMOD produce three reports; flight performance report which shows the planned and actual aircraft used, departure time and arrival time of each flight. It also shows statistics on delay times (original, reactionary and total delays). Aircraft utilization report is a daily report illustrates the utilization of each aircraft and the status of aircraft at the end of the day.

Daily performance summary report shows summarized statistics on schedule, delay function, delays and punctuality for more than 0 minute and delays and punctuality for more than 15 minutes.

Schedule performance summary report is produced at the end of schedule simulation. This report illustrates summary statistics on schedule, delay

function, punctuality for 0 or 15 minutes, strategies used for this simulation and the average daily delay time.

Output of each simulation run is **400 pages long** and occupies about **1.2 megabytes of disk space**. Therefore all the outputs for the eighteen strategies are stored in floppy diskettes and a small programs are written to summarize these outputs. Sample of these reports are shown previously in chapter (6).

7.4.1 Results for Strategy Set # 1:

For the following parameters:

Scheduled Ground Times	=	30 minutes
Fleet including spare	=	9 aircraft
Total Departures during simulation time	=	11200 flights
Total Block Hours during simulation time	=	12816.7 hours

The results are summarized for all delays which are more than one minute delay in **table (7-1)** and serious delays more than 15 minutes in **table (7-2)**.

Table (7-1) shows the summary statistics of **all delays** (i.e. any flight delay more than 0 minutes) including total delay frequencies, total delay time of the total simulation time for each strategy (MDAS). Also average delay time per day and total spare block hours used in the strategy during the simulation period are shown. It illustrates that strategy # 1 has the minimum total delays and delay time and average delay time while it has the maximum spare block hours used in this simulation.

Table (7-1) All Delays

MDAS in Hours	Total Delays	Delay Time	Average Delay/day	Spare Block Hours
1	3633	3212	16.1	745.15
2	3746	3627	18.1	341.34
3	3763	3842	19.2	167.03
4	3772	3920	19.6	73.97
5	3767	3944	19.7	39.59
6	3771	3957	19.8	36.66

Table (7-2) shows the summary statistics of **serious delays** (i.e. any flight delay more than 15 minutes) including total delay frequencies, total delay time and average delay time per day of the total simulation time for each strategy (MDAS). Range of daily average delay of all delays is between 16.1 to 19.8 compared to 15.5 to 19.3 hours for the serious delays. Range of serious delays is between 2748 to 2919 delays compared to 3633 to 3771 delays for all delays.

Table (7-2) Serious Delays

	SERIOUS MDASDelays	Delay Times	Average Delay/day
1	2748	3105	15.5
2	2894	3524	17.6
3	2907	3738	18.7
4	2919	3817	19.1
5	2916	3841	19.2
6	2919	3853	19.3

Figure (7-1) shows the total delay frequencies including both all delays and serious delays by each strategy of MDAS used in the SKDMOD simulation model. As shown in the figure, when using 2 to 6 hours MDAS and 30 minutes ground times, (second to the sixth strategy), all and serious delay frequencies are approximately the same except for one hour MDAS (first strategy) where the delays are clearly much less.

Figure (7-2) shows the total delay time occurred during the entire simulation period, as found from figure (7-1) that one hour MDAS has the minimum delay frequencies. It is also true for total delay time. Although total delays are similar for 2 to 6 hours of MDAS but the delay times for those strategies are different as appears in figure (6-2). Total delay time increase gradually as MDAS between 1 to 5 hours then delay time starts stabilizing after MDAS of 5 hours in this set of strategy.

Figure (7-3) shows the daily average delay time for the first six strategies.

Figure (7-1) Delay Frequencies for Strategy Set # 1

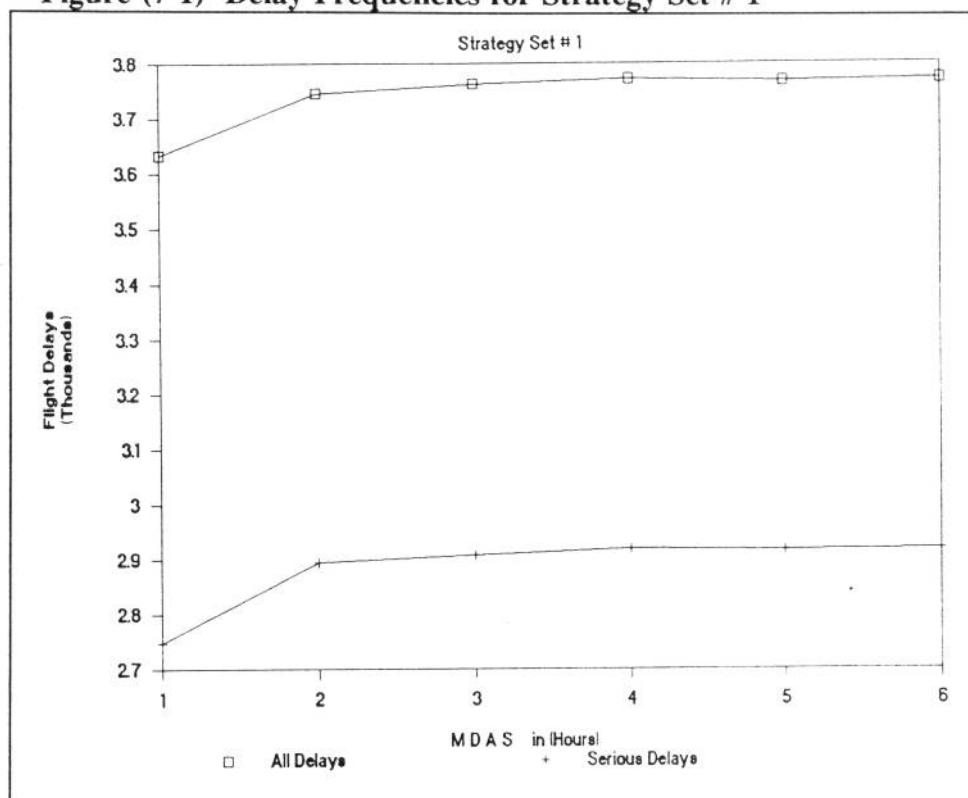


Figure (7-2) Delay Time for Strategy Set # 1

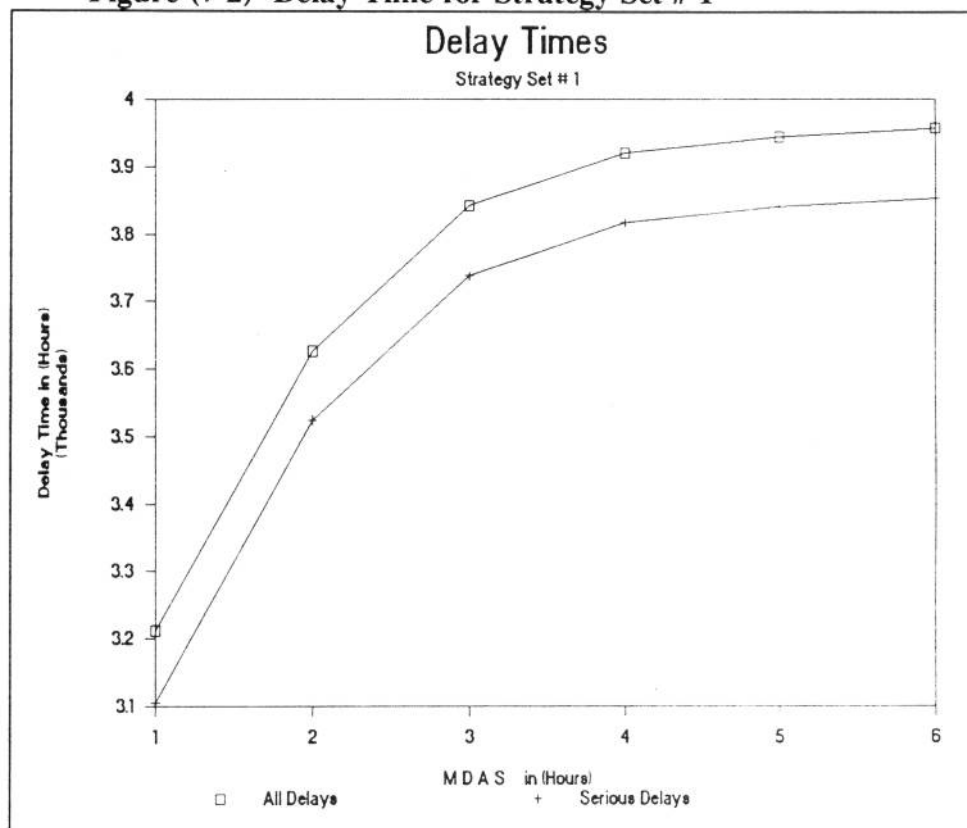


Figure (7-3) Average Daily Delay Time for Set # 1

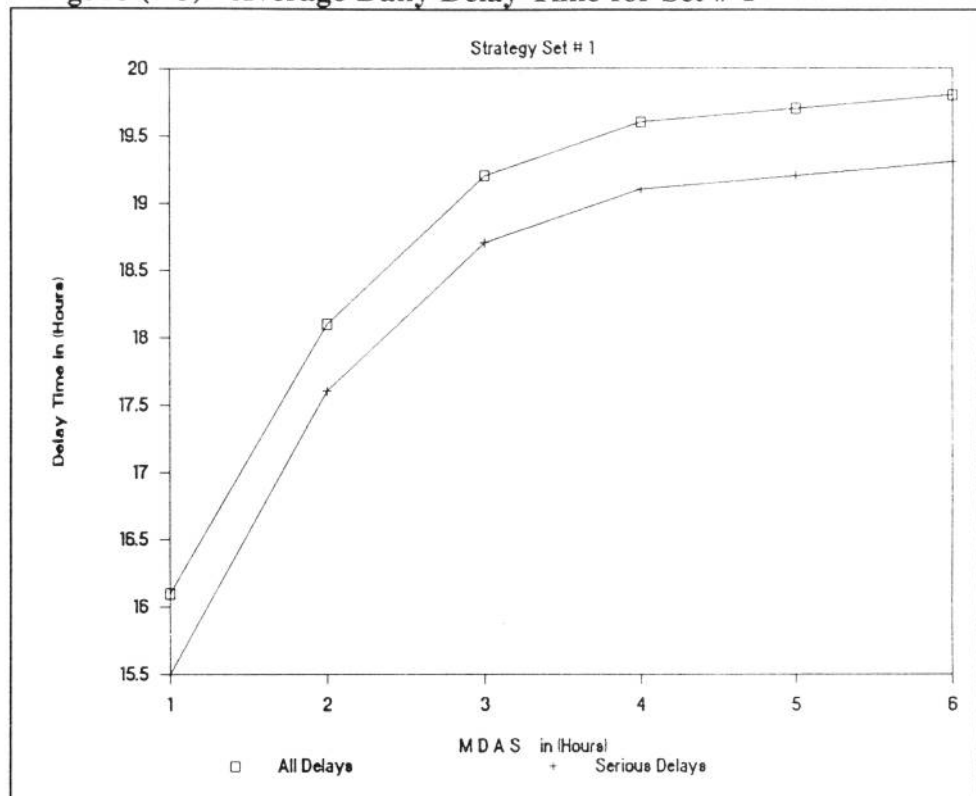


Figure (7-4) Spare Block Hours for Strategy Set # 1

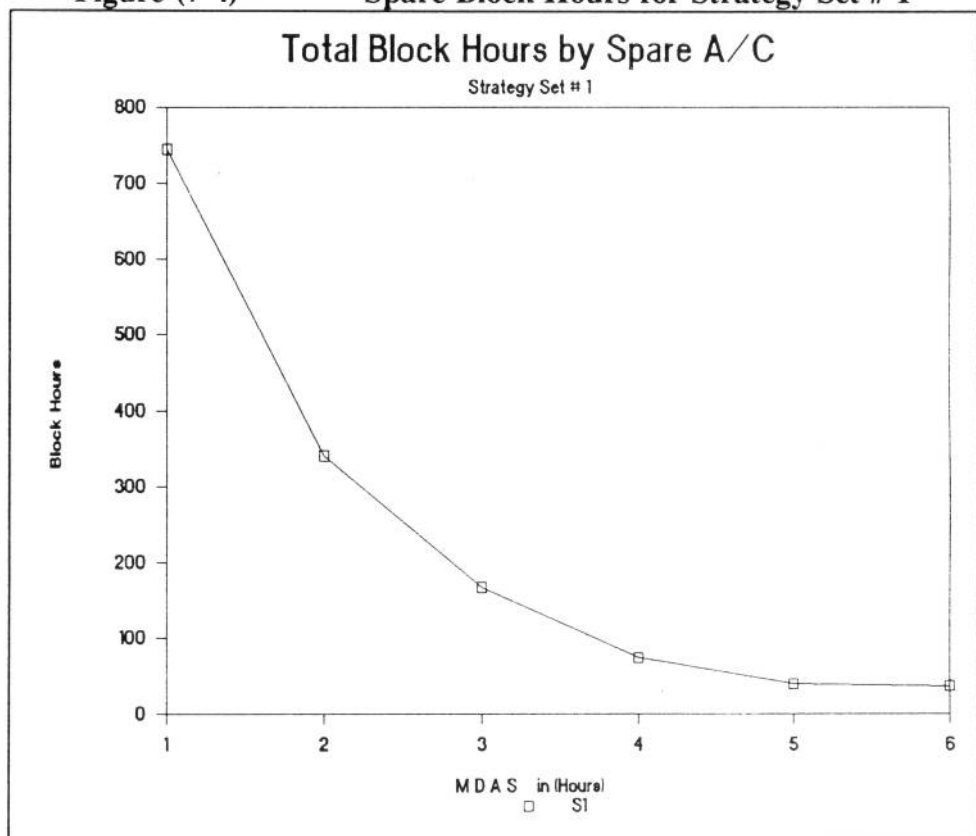


Figure (7-4) illustrates the total spare block hours utilized by each strategy. It is clear that strategy # 1 has the maximum number of used spare block hours (745 hours using two spare aircraft) because of the low MDAS value (MDAS = 1 hour). As MDAS values increases the utilization of the spare becomes less i.e. the sixth strategy where MDAS = 6, the utilization of the spare is 37 hours.

7.4.2 Results for Strategy Set # 2:

For the following parameters:

Scheduled Ground Times	=	40 minutes
Fleet including spare	=	10 aircraft
Total Departures during simulation time	=	11200 flights
Total Block Hours during simulation time	=	12816.7 hours

The results are summarized for all delays which are more than 0 minute in table (7-2) and serious delays more than 15 minutes in table (7-3). This is accomplished using SKDMOD for all the simulation period (200 days) and the above mentioned inputs in respect to the ground time and spare aircraft.

Table (7-3) illustrates the summary statistics for the second set of strategy (strategy # 7 to strategy # 12). Strategy # 7 has the minimum values of total delay, delay time and daily average delay but it also has the maximum value of the spare block hours used. Average daily delay time of all delays is ranging between 15 to 17.5 hours compared to 16 to 19.8 in the first set of strategy. Similarly strategy # 7, which has the maximum spare block hours, has 500 hours spare compared to strategy # 1 which has 745 hours.

Table (7-3) All delays

MDAS in Hours	Total Delays	Delay Time	Average Delay/day	Spare Block Hours
1	3338	3021	15.1	500.5
2	3399	3270	16.4	256.32
3	3418	3407	17.1	32.08
4	3429	3458	17.3	60.65
5	3432	3480	17.4	31.41
6	3432	3497	17.5	31.41

Table (7-4) shows the summary statistics of **serious delays** (i.e. any flight delay more than 15 minutes) of the second set of strategies including total delay frequencies, total delay time and average delay time per day of the total simulation time for each strategy (MDAS). Range of daily average serious delay time between *14.6 to 17 hours compared to 15.1 to 17.5* for all delays. Range of serious delays is between *2537 to 2633 delays compared to 3338 to 3432 delays* for all delays for this set of strategy.

Table (7-4) Serious Delays

	<u>SERIOUS</u> <u>MDASDelays</u>	<u>Delay</u> <u>Times</u>	<u>Average</u> <u>Delay/day</u>
1	2537	2926	14.6
2	2595	3174	15.9
3	2623	3312	16.6
4	2631	3362	16.8
5	2633	3384	16.9
6	2633	3401	17

Figure (7-5) shows the total delay frequencies including both all delays and serious delays by each strategy of MDAS used in the SKDMOD simulation model. Using 2 to 6 hours MDAS strategy with 40 minutes (7th to the 12th strategy), all and serious delay frequencies are approximately the same except for one hour MDAS (first strategy) where the delays are less.

Figure (7-6) shows the total delay time occurred during the entire simulation period, as found from figure (7-5) that one hour MDAS has the minimum delay frequencies it is also true for total delay time. Although total delays are similar for 2 to 6 hours of MDAS but the delay times are different as appears in figure (7-6). Total delay time increase gradually as MDAS between 1 to 5 hours then delay time starts stabilizing after MDAS of 5 hours in this set of strategy.

Figure (7-7) shows the daily average delay time for the second six strategies.

Figure (7-5) Delay Frequencies for Strategy Set # 2

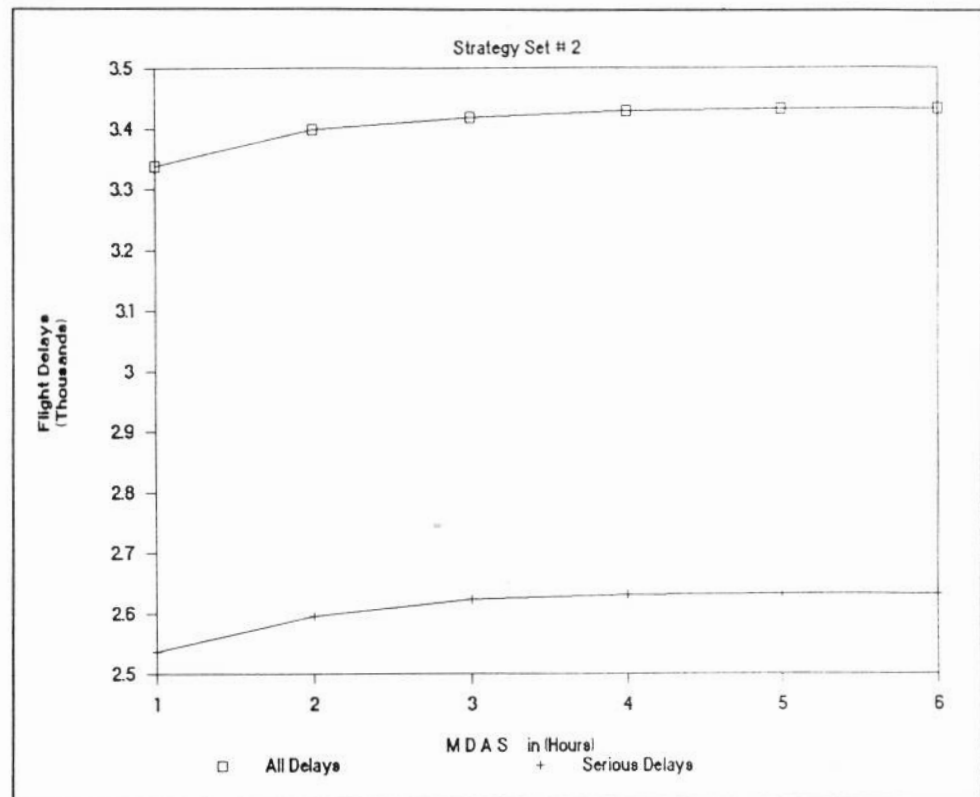


Figure (7-6) Delay Time for Strategy Set # 2

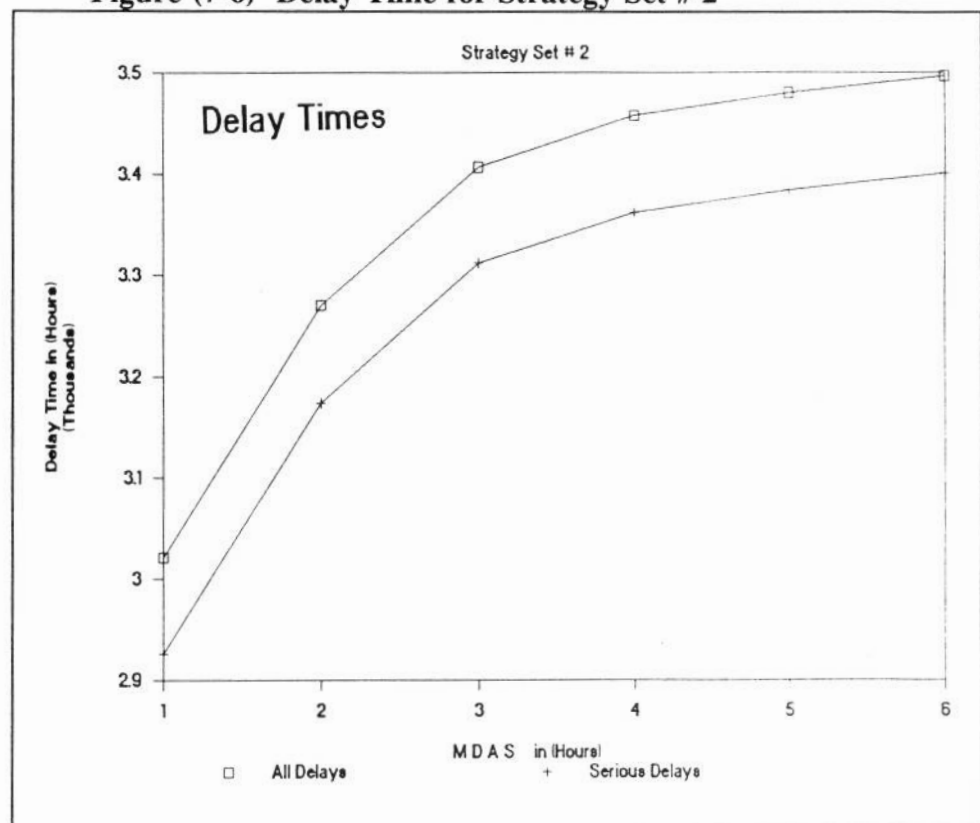


Figure (7-7) Average Daily Delay Time for Set # 2

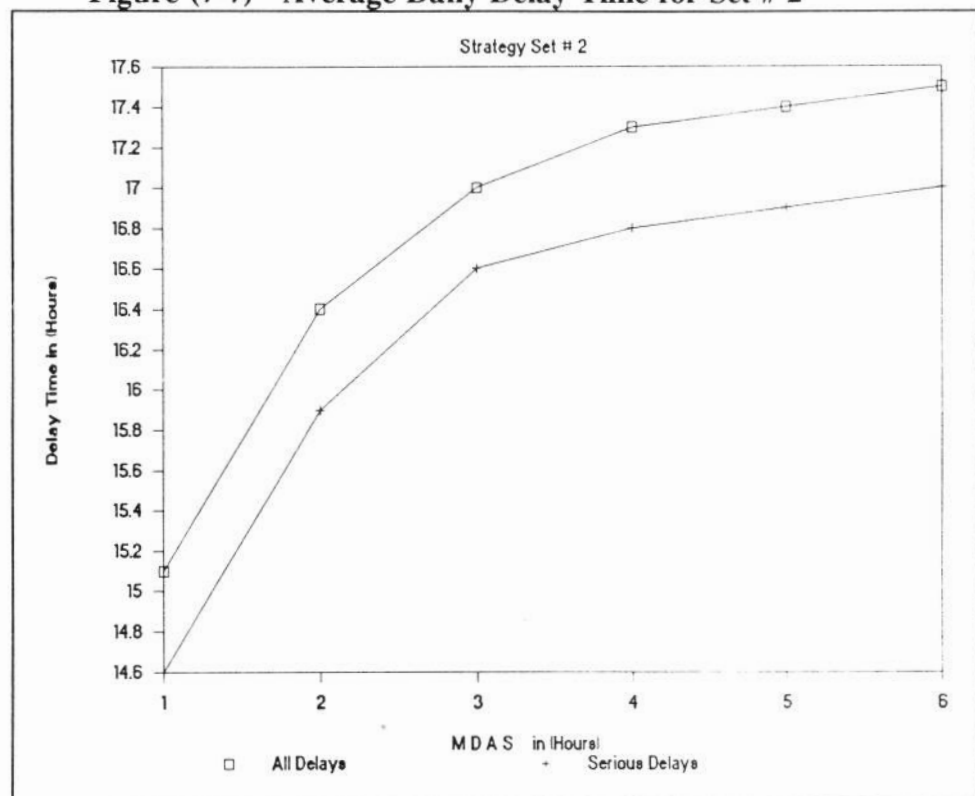


Figure (7-8) Spare Block Hours for Strategy Set # 2

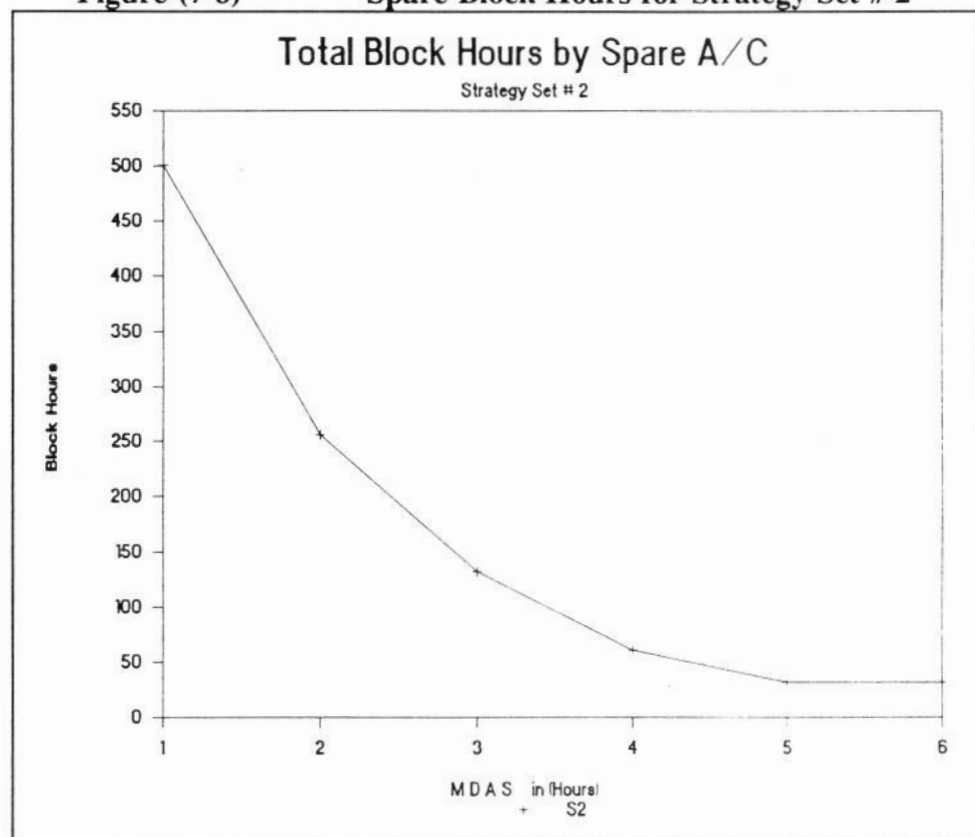


Figure (7-8) illustrates the total spare block hours utilized by each strategy. It is clear that strategy # 7 (first strategy in this set) has the maximum number of used spare block hours (500 hours using two spare aircraft) because of the low MDAS value ($\text{MDAS} = 1$ hour). As MDAS values increases the utilization of the spare becomes less i.e. the sixth strategy in this set where $\text{MDAS} = 6$ (strategy # 12), the utilization of the spare is 37 hours.

7.4.3 Results for Strategy Set # 3:

For the following parameters:

Scheduled Ground Times	=	50 minutes
Fleet including spare	=	11 aircraft
Total Departures during simulation time	=	11200 flights
Total Block Hours during simulation time	=	12816.7 hours

The results are summarized for all delays which are more than 0 minute delay in table (7-5) and serious delays more than 15 minutes in table (7-6).

Table (7-5) illustrates the summary statistics for the third set of strategies (strategy # 13 to strategy # 18). Strategy # 13 has the minimum values of total delays, delay time and daily average delay but it also has the maximum value of the spare block hours used. Average daily delay time of all delays is ranging between 14.4 to 15.8 hours compared to 15.1 to 17.5 hours in the second set of strategy and compared to 16.1 to 19.8 in the first set of strategy. Similarly strategy # 13, which has the maximum spare block hours, has 368 hours spare compared to 500 hours spare in strategy # 7 and compared to 745 hours in strategy # 1.

Table (7-5) All Delays

MDAS in Hours	Total Delays	Delay Time	Average Delay/day	Spare Block Hours
1	3172	2886	14.4	368.45
2	3193	3052	15.3	166.37
3	3200	3122	15.6	64.98
4	3199	3145	15.7	43.9
5	3197	3160	15.8	18.49
6	3200	3167	15.8	18.49

Table (7-6) shows the summary statistics of **serious delays** (i.e. any flight delay more than 15 minutes) of the third set of strategies including total delay frequencies, total delay time and average delay time per day of the total simulation time for each strategy (MDAS). Range of daily average serious delay time between *14 to 15.4 hours compared to 14.6 to 17 hours in the second set of strategy and compared to 15.5 to 19.3* for the first set of strategy. Range of serious delays is between *2409 to 2442 delays compared to 3172 to 3200 delays* for all delays for this set of strategies.

Table (7-6) Serious Delays

	<u>SERIOUS</u> <u>MDAS Delays</u>	<u>Delay</u> <u>Times</u>	<u>Average</u> <u>Delay/day</u>
1	2409	2796	14
2	2439	2963	14.8
3	2442	3032	15.2
4	2441	3055	15.3
5	2439	3070	15.4
6	2442	3076	15.4

Figure (7-9) shows the total delay frequencies including both all delays and serious delays by each strategy of MDAS used in the SKDMOD simulation model. Using 2 to 6 hours MDAS strategy with 50 minutes (13th to the 18th strategy), all and serious delay frequencies are approximately the same except for one hour MDAS (first strategy in this set) where the delays are little less.

Figure (7-10) shows the total delay time occurred during the entire simulation period, as found from figure (9) that one hour MDAS has the minimum delay frequencies it is also true for total delay time. Although total delays are similar for 2 to 6 hours of MDAS but the delay times are different as appears in figure (10). Total delay time increase gradually as MDAS between 1 to 5 hours then delay time starts stabilizing after MDAS of 5 hours in this set of strategy.

Figure (7-11) shows the average delay time per day for the third set of six strategies.

Figure (7-12) illustrates the total spare block hours utilized by each strategy. It is clear that strategy # 13 (first strategy in this set) has the

Figure (7-9) Delay Frequencies for Strategy Set # 3

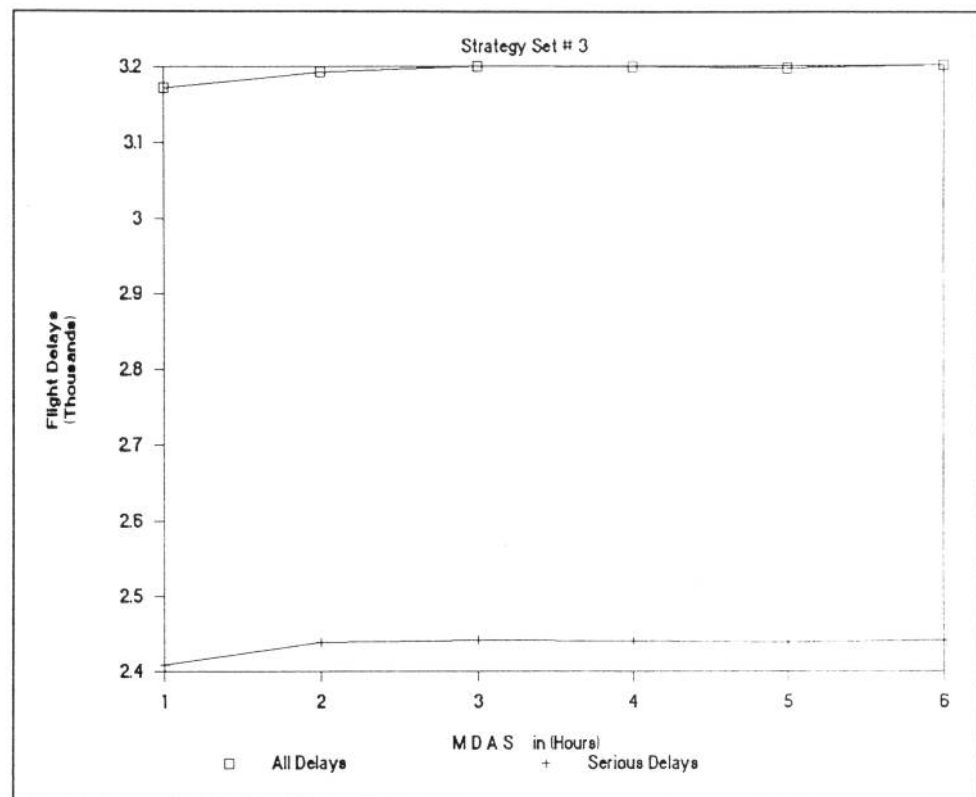


Figure (7-10) Delay Time for Strategy Set # 3

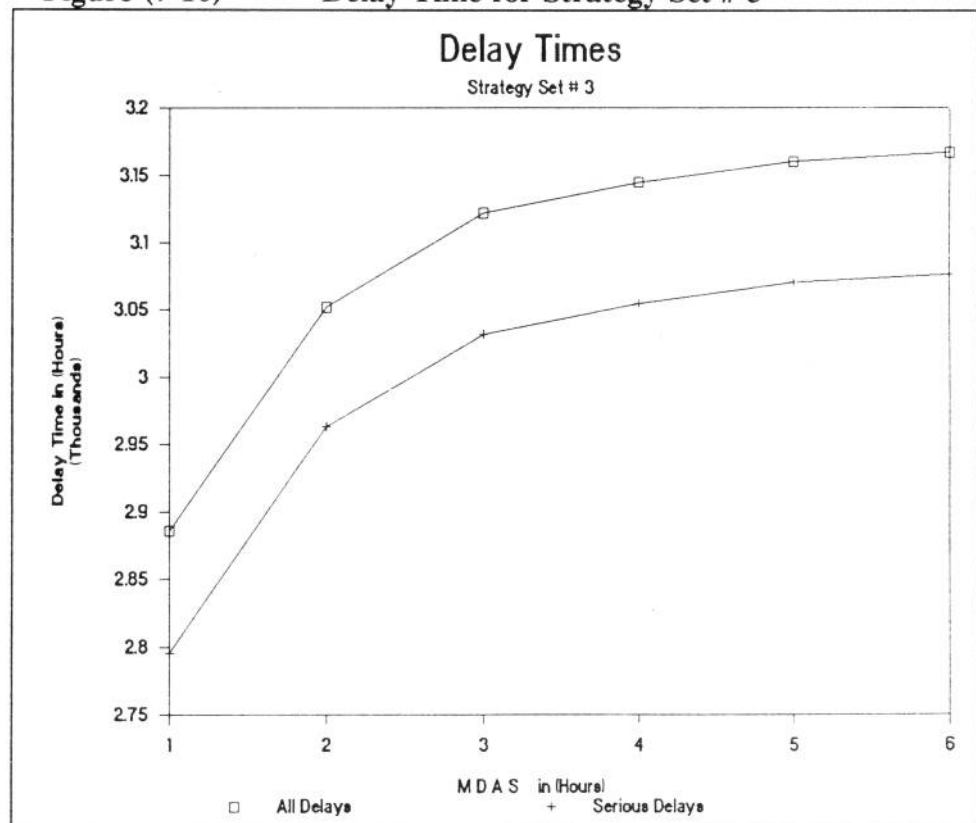


Figure (7-11) Average Daily Delay Time for Set # 3

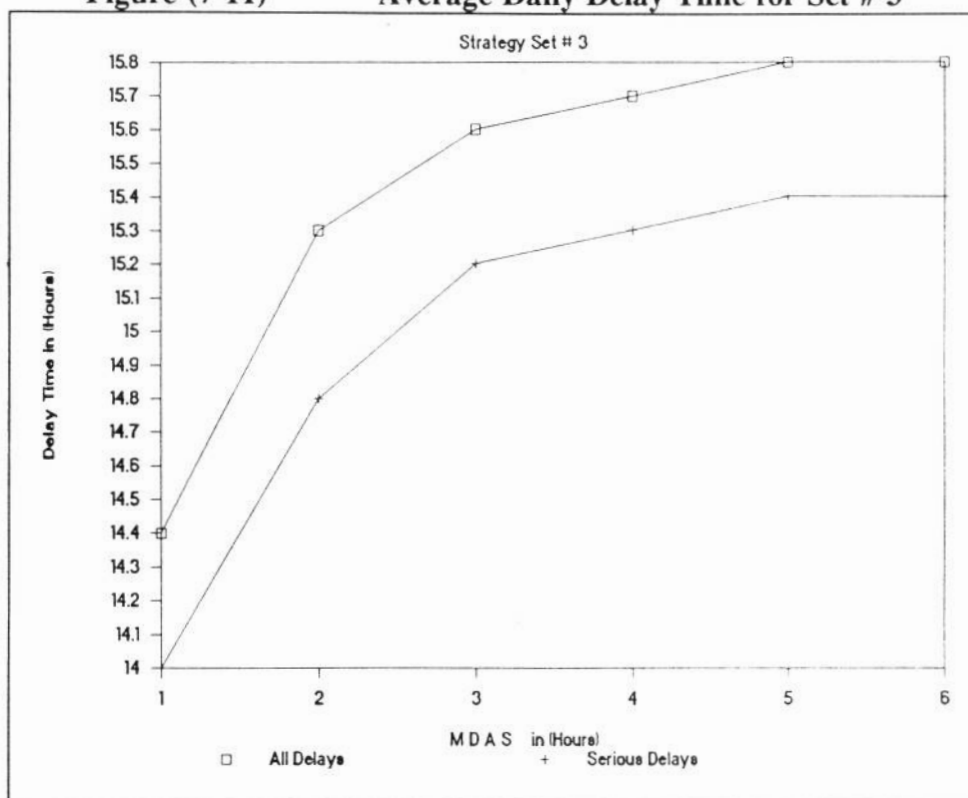
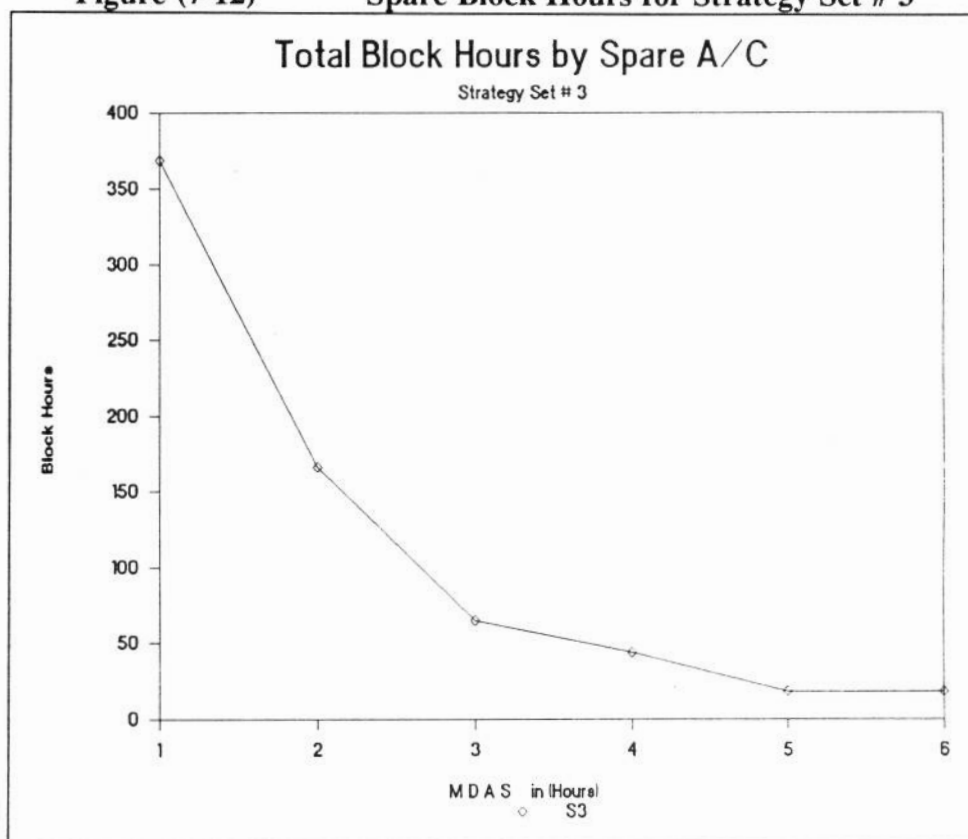


Figure (7-12) Spare Block Hours for Strategy Set # 3



maximum number of used spare block hours (368.5 hours using two spare aircraft) because of the low MDAS value ($\text{MDAS} = 1$ hour). As MDAS values increases the utilization of the spare becomes less i.e. the sixth strategy in this set where $\text{MDAS} = 6$ (strategy # 18), the utilization of the spare is 18.5 hours.

7.5 CONCLUSION:

In conclusion of the simulation analysis, delay frequencies, delay time, average daily delay and spare block hours utilization are summarized in the following sections. "SKDMOD" is a prototype aircraft schedule simulation model. It is used with delay function determined earlier in chapter (4). Three different schedule plans are used for simulation illustrating three ground times (30, 40 and 50 minutes as a schedule ground time where the scheduled ground time equals minimum ground time plus the slack ground time where minimum ground time equals 30 minutes). For each schedule plan, six MDAS (Maximum Delay to Assign Spare aircraft) strategies are simulated to determine the impact of the MDAS on the entire punctuality. Two spare aircraft are available for spare operations whenever it is needed, SKDMOD has the logic of assignment of a spare aircraft in "assign spare aircraft" process. For the analysis purposes the utilization of these spare aircraft is accumulated in terms of block hours throughout the entire simulation period (200 days) for each strategy (18 strategies). Delays are classified as a delay or a serious delay. Assumed in SKDMOD model is that any delay which is equal or greater than one minute is accumulated under 'all delays' and any delay equal or greater than 15 minutes is accumulated under 'serious delays'. So the analysis is shown here in terms of 'all' and 'serious' delays.

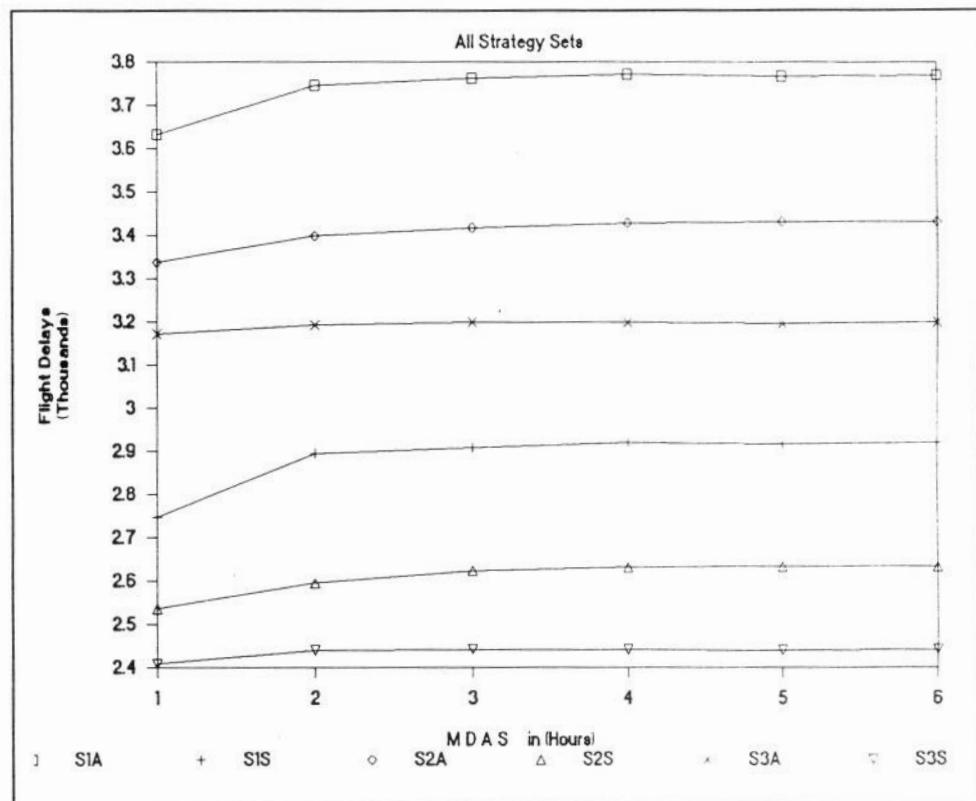
7.5.1 Delay Frequencies:

Figure (7-13) shows the delay frequencies of all strategies in all sets of strategies (18 strategies) including all and serious delays.

The three top lines represents all delays for the three sets of strategies. S1A line represents all delays of the first set of strategies (1st to 6th strategy) which have the highest frequency of delays (about 3750 delays per strategy simulated for 200 days). S2A line represents all delays of the second set of strategies (7th to 12th strategy) which have the second highest frequency of delays (about 3400 delays per strategy simulated for 200 days). S3A line represents all delays of the third set of strategies (13th to 18th strategy) which have the third highest frequency of delays (about 3175 delays per strategy simulated for 200 days).

The three bottom lines represents the serious delays for the three sets of strategies. S1S line represents the serious delays of the first set of strategies which have the highest frequency of serious delays (about 2900 delays per strategy simulated for 200 days). S2S line represents the serious delays of the second set of strategies which have the second highest frequency of serious delays (about 2600 delays per strategy simulated for 200 days). S3S line represents the serious delays of the third set of strategies which have the third highest frequency of serious delays (about 2430 delays per strategy simulated for 200 days).

Figure (7-13) Delay Frequencies for all Strategies



7.5.2 Delay Times:

Figure (7-14) illustrates the delay times for all strategies (three sets). Strategies in the first set (1st to 6th strategy) have the longest delay time through the entire simulation period (200 days). Strategies in the second set (7th to 12th strategy) have the second longest delay time through the entire simulation period. While strategies in the third set (13th to 18th strategy) have the shortest delay time through the entire simulation period. There is a similar gap, approximately 100 hours, between all and serious delay time lines in the three sets of strategies.

Figure (7-14) Delay Times for All Strategies

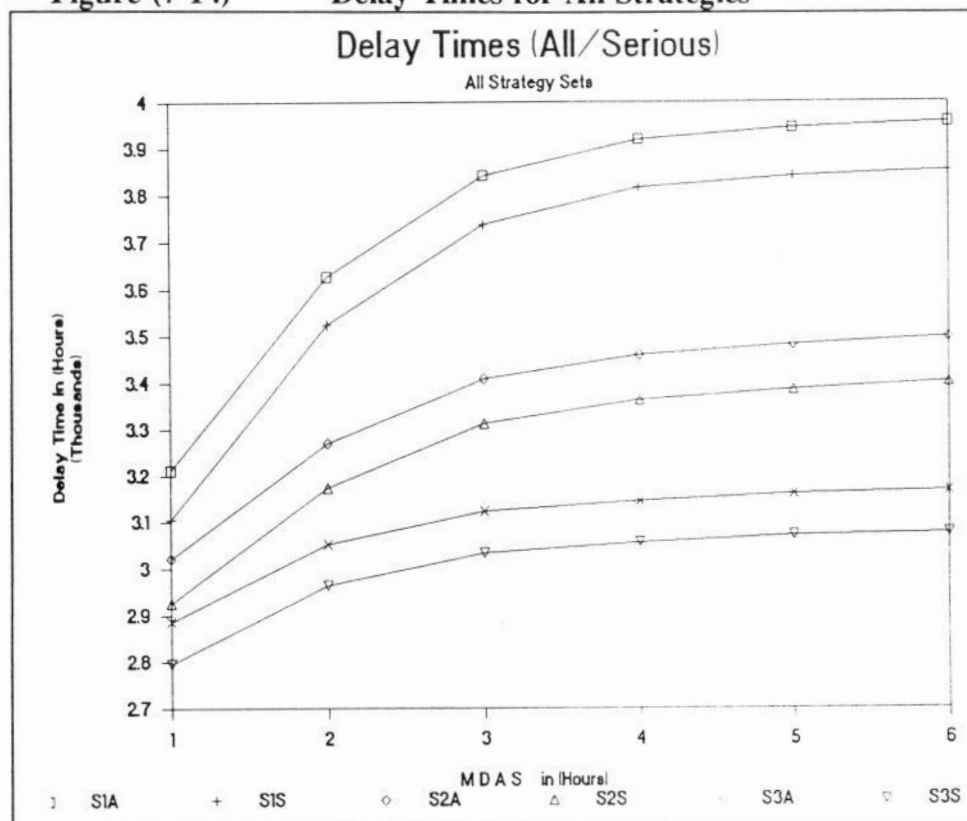
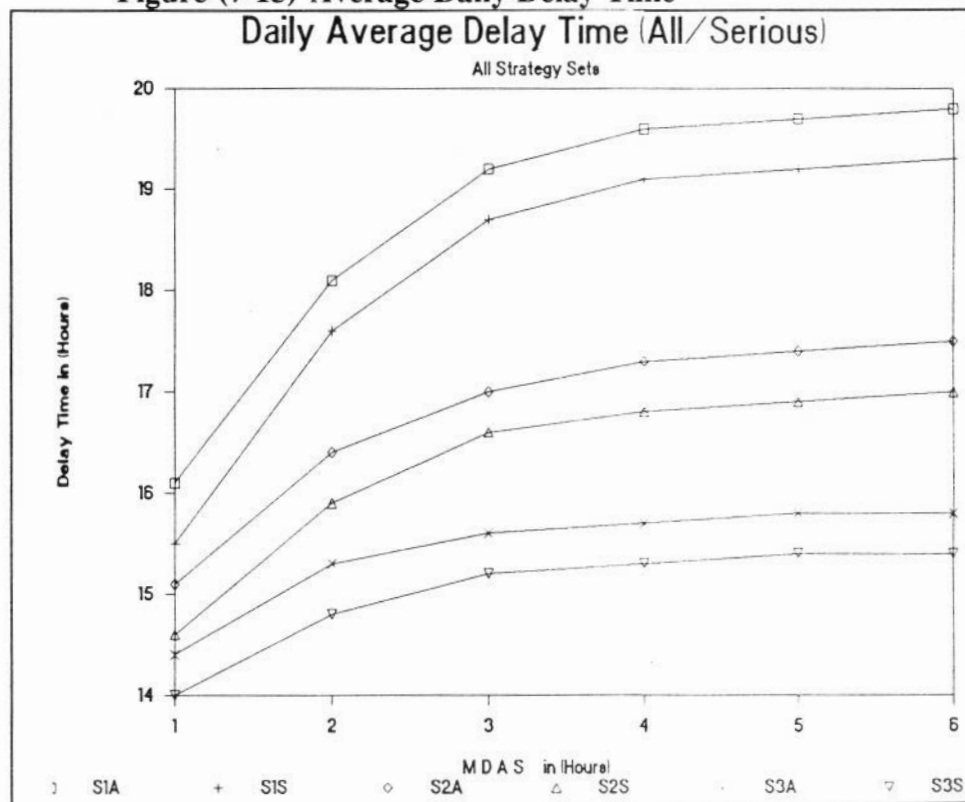


Figure (7-15) Average Daily Delay Time



7.5.3 Average Daily delay Time:

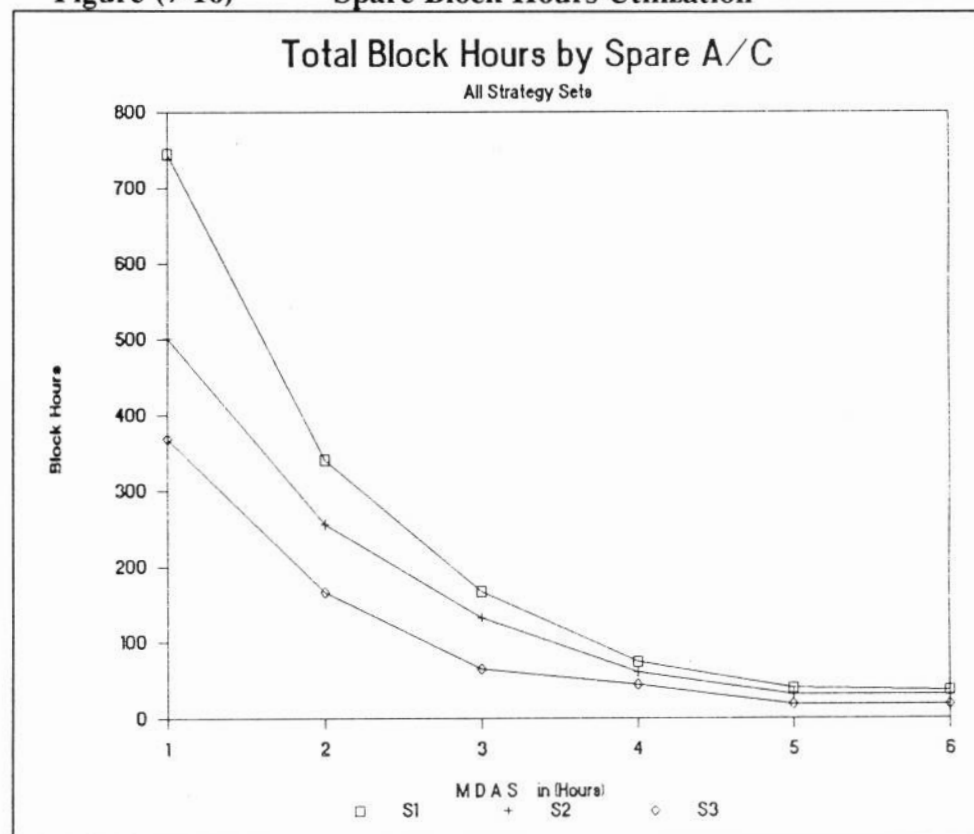
Figure (7-15) shows the average delay time for all strategies. A similar pattern of delay times discussed in figure (7-14) and the gap between all and serious delays is approximately 0.5 hour of the average daily delay time.

7.5.4 Spare Block Hours Utilization:

Figure (7-16) illustrates the utilization of the spare aircraft (two spare aircraft included in each active fleet of the three schedule plans). Strategy set # 1 has a total fleet of 9 aircraft including two as a spare, strategy set # 2 has a total fleet of 10 aircraft including two as a spare and strategy set # 3 has a total fleet of 11 aircraft including two as a spare.

As appears in figure (7-16) that the highest utilization of the spare fleet exists in the first set of strategies (1st to 6th strategy), the second highest exists in the second set (7th to 12th) and the lowest utilization exists in the third set of strategies (13th to 18th).

Figure (7-16) Spare Block Hours Utilization



It is noticeable that for all strategies which their **MDAS values are greater than or equal to 4 hours**, there exists minor difference in the utilization of spare aircraft. On the other hand for MDAS values less than 4 hours there exists a major difference in the spare aircraft utilization especially for MDAS equal to one/two hour(s).

Scheduled ground times influence the required active fleet because the more ground time planned in the aircraft rotation plan or aircraft cycle the more aircraft hours are needed to run the same schedule. This leads to more availability of aircraft during the operating hours due to lower aircraft utilization. This is clearly reflected in the delay times and average daily delay time. Also the utilization of spare aircraft also shows the impact of different ground times. In all strategies with MDAS values less than 4 hours the spare aircraft utilization is high and required, but for those strategies which has MDAS values greater than/equal to 4 hours the utilization of the spare aircraft is low.

Of course there is another feature to the high/low utilization, the extra operating cost due to the extra active aircraft (one extra aircraft for the second set of strategies and two extra aircraft for the third set of strategies). Similarly there is an extra operating cost for the spare block hours utilized. On the other hand, passengers are impacted from delays and there exists a percentage loss of revenue passengers. The optimization of the extra operating cost and the passenger revenue loss is subject to mathematical formulation and analysis in chapter (8).

CHAPTER 8

FORMULATION OF PUNCTUALITY MANAGEMENT OPTIMIZATION

APPROACH

As discussed in chapters (1) and (7) all punctuality management strategies have an impact on the airline operating cost and on operating revenue. Planning strategies are; provide more slack time in flight duration 'as a part of block time' and more slack time in the ground time 'as a part of scheduled ground time'. Operational strategies are; provision of additional spare aircraft, improve the preventative maintenance procedure and increase quantity and/or quality of ground support equipments and crews. These strategies will increase the operating cost but it will also improve the airline schedule punctuality. Improving schedule punctuality will increase passenger's satisfaction which will improve the airline operating revenue.

This chapter illustrates the mathematical formulation of Punctuality Management (PM) decision criteria used in PM optimization. The resultant optimization approach helps the airline management select the **best strategy** for schedule planning. In addition to the ability to compare between different strategies, considering the previous findings regarding passengers revenue loss in case of delays and the extra cost which is due to the improvement in providing more aircraft to run the schedule and other airline resources on ground. The optimization is also based on the results found from strategy simulation in regard to the needs to spare aircraft and its utilization. More elaboration on the objective of this chapter is in section 8.1. Section 8.2 explains the background of the optimization criteria considered. Section 8.3 shows the basic mathematical formulation for the decision criterion in terms of revenue and cost. Section 8.4 derives the formulation for the profit criterion and profit margin criterion. Section 8.5 describes the decision making approach for determination of the best schedule punctuality management strategy.

8.1 INTRODUCTION:

The objective is to formulate a mathematical model that enables the airline to optimize its management strategies and determine the best strategy based on basis of *profit* or *profit margin*.

This formulation is based on the operating cost and passengers' revenue relationships using *variable values and variable ratios* which give the formulation global relevance in terms of sensitivity and in depth analysis. Also the formulation is generic and can be adopted to other airlines. Generally, the alternative approach is to determine the profit or profit margin for specific strategies by using a specific airline's data to evaluate operating cost or operating revenue. This approach can be accomplished directly by evaluating the operating costs based on the block hour cost and the operating revenue based on the average ticket value or based on the average yield. These values are subject to discussion and changes based on different operational constraints and environmental changes. Of course, in some airlines, actual data is not only different from one airline to another but it is also different from region to region in the same airline.

8.2 OPTIMIZATION CRITERIA:

Two types of decision criteria are considered in this research; profit and profit margin.

In this formulation, in order to make the optimization more generic, different financial ratios such as revenue to cost of an airline are considered and block hour cost of schedule operation to block hour cost of spare operation is considered. These ratios cover more scope especially when applying sensitivity analysis.

8.2.1 Profit Decision Criterion:

This criterion compares one strategy with other strategies to evaluate which is better in terms of profit. The profit of the schedule equals the revenue minus the cost of the schedule when using a specific strategy. *The higher the profit the better the strategy.*

All strategies are compared by considering different values or range of values of decision criterion. Best strategies are determined based on profit criterion i.e. if revenue loss or revenue to cost ratio is changed then optimum strategies might also change. The advantage is the ability to determine the best strategy on the same basis for different airlines. In other words, the data used in calculating this criterion is not based on a single airline. Revenue to cost ratio is used in development of this decision criterion. Another advantage within the same airline is determination of the sensitivity analysis of best strategy given other parameters which will be discussed in more details later in this chapter.

8.2.2 Profit Margin Decision Criteria:

This decision criterion focuses on one strategy and determines the value of the profit margin for a strategy. The division of the profit over the revenue of a strategy will determine the profit margin for that strategy. Profit margin gives the ratio of the profit gained from one dollar revenue (if dollar is the unit of currency).

Also this criterion is formulated as a function of different cost and revenue parameters which give the ability to perform sensitivity analysis on these parameters.

Both criteria are used here in evaluating the strategies. The profit criterion gives in absolute value the amount of the profit made by adopting a strategy. The unit of this value is the unit of the currency used in the system. The profit margin criterion gives the ratio of the profit made in one unit of revenue. Strategies can be compared easier with profit margin. *The higher the profit margin the better the strategy.*

8.3 BACKGROUND OF DECISION CRITERION FORMULATION:

In this section, revenue and cost are derived to formulate a portion of the equations used later in the decision criterion formulae. In each part of revenue and cost, detailed definitions are explained. First the notation used in formulation is defined and discussed.

8.3.1 Revenue Formulation:

As discussed earlier in strategy simulation results (Chapter 7) in this research we have 18 different strategies. Each strategy has different values of maximum delay to assign spare aircraft (MDAS) and different ground times as slack times. So each strategy has a different punctuality performance and different spare aircraft utilization. These factors have an impact on revenue and cost of the airline. Three sets of schedules each with different planned ground time (30 minutes, 40 minutes and 50 minutes). Each set has six different values for MDAS (maximum delay time to assign spare aircraft). So strategies are S_i where $i = 1, 2 \dots 18$ strategies.

So strategy set (1) with planned ground time equals 30 minutes have strategies 1 to 6 (from S_1 to S_6). Strategy Set (2) includes all strategies with ground time equals 40 minutes (from S_7 to S_{12}) and strategy set 3

includes all strategies with ground time equals 50 minutes (from S_{13} to S_{18}). So:

Strategy Set 1 = S_i , $i = 1, 2, \dots, 6$

Strategy Set 2 = S_i , $i = 7, 8, \dots, 12$

Strategy Set 3 = S_i , $i = 13, 14, \dots, 18$

So each strategy has different punctuality performance and different spare aircraft utilization/requirements. These factors have an impact on revenue and cost of the airline.

Notation:

R = Total operating revenue without delays in Dollars (\$).

R_i = Total operating revenue using strategy i in Dollars (\$).

L_i = Total revenue loss due to delays using strategy i in Dollars (\$).

RL_i = Percentage of revenue loss using strategy i which is defined as

$$RL_i = \frac{L_i}{R}$$

Mathematical Formulation:

Total revenue loss in a schedule using strategy i equals total operating revenue at normal conditions minus total operating revenue of the schedule using strategy i .

$$L_i = R - R_i$$

$$\text{Then } R_i = R - L_i \quad (1)$$

As defined RL_i is the percentage of revenue loss by using strategy i :

$$RL_i = \frac{L_i}{R}$$

$$\text{Then } L_i = R \cdot RL_i \quad (2)$$

By substitute equation (2) in equation (1).

$$R_i = R - R \cdot RL_i$$

Then

$$R_i = R (1 - RL_i) \quad (3)$$

From the passenger attitude survey towards punctuality developed in chapter (5), the impact function $I(t)$ is found from the survey findings. The impact function has a minimum value of "1" and a maximum value of "5" as indicated in the questionnaire scale "no impact " and "very serious impact" respectively. Estimates of passengers revenue loss are developed using the revenue loss function found from the survey. The maximum revenue loss percentage (MRL), which will be input interactively in the optimization program as an indication of revenue loss, is found for general passengers, vacationers and business passengers. The new function is the revenue loss function $XL(T)$, in percentages which gives a percentage loss of revenue for a delay time.

For each strategy, reference to the simulation results mentioned in chapter (7) a detailed histogram is developed which shows the delay frequencies for a range of delay times. This delay histogram determines the delay frequency for an interval of delay time $FD(T)$. Then percentage loss in revenue $RL(T)$, based on interval (T) of the delay time range, is found after schedule simulation in SKDMOD model. Frequency of delays at that interval time is calculated to determine the percentage revenue loss at the mid point of that delay range $XL(T)$.

$$RL(T) = FD(T) \cdot XL(T) \quad (4)$$

Then the revenue loss percentage for a strategy i (RL_i) is calculated by summing all the revenue loss of all delay intervals and normalized.

$$RL_i = \frac{\sum RL(T)}{SF \cdot 100} \quad (5)$$

where

SF = total schedule flights over the entire simulation.

This approach approximates the percentage revenue loss but it depends mainly on passengers responses during the survey. As discussed in Chapter 5 that this approach has a weakness of using the maximum revenue loss function the way it is because this function includes both the passenger loss and the passenger trip loss.

8.3.2 Cost Formulation:

Notation:

C = Total operating cost without delays in Dollars (\$) for the base schedule using minimum schedule aircraft requirement.

= A . H

where

A = Block hour cost at no delay conditions.

H = Block hours of the total schedule performed by schedule aircraft.

$(C_i)_0$ = Total operating cost of schedule using strategy i without delays in Dollars (\$). o is a designator for the base schedule cost without delays. This cost for a schedule with seven aircraft or more if strategies are from strategy set 2 or strategy set 3 where respectively the planned schedule required eight and nine aircraft.

$$= A_i \cdot H$$

Where

A_i = Block hour cost at no delay conditions using strategy i .

J_i = Adjusting cost related factor for strategies with different operational aircraft in the schedule. For strategy i the factor J_i will be

$$J_i = 1 \text{ for } i = 1, 2 \dots 6 \quad (7 \text{ A/C}),$$

$$J_i > 1 \text{ for } i = 7, 8 \dots 12 \quad (8 \text{ A/C}), \text{ and}$$

$$J_i > 1 \text{ for } i = 13, 14 \dots 18 \quad (9 \text{ A/C}).$$

Thus the adjusting factor (J_i) is set for each schedule (set of strategies) where the number of required operational aircraft is different. For example the first six strategies (Strategy Set 1) use a schedule based on 30 minutes ground time. The second six strategies (Strategy Set 2) are using a schedule with 40 minutes ground time and similarly the third six strategies (Strategy Set 3) are using schedule based on 50 minutes ground time. Operational aircraft required are 7 aircraft for the first set of strategies, 8 aircraft for the second set and 9 aircraft for the third set of strategies. So the adjusting factor (J_i) compensates for the additional operational aircraft. There are three adjusting factor values corresponding to each schedule or set of strategies. The adjusting factor value of the base strategy 'set one' equals 1. Then $(C_i)_0$ is

$$(C_i)_0 = J_i \cdot A \cdot H \quad (6)$$

B = Block hour cost of operations made by spare aircraft due to delays occurrence in (dollar/hour).

This hourly cost (B) is higher than the normal hourly cost defined earlier (A). This extra cost is due to ownership of spare aircraft, hull insurance, depreciation and hull maintenance of the spare aircraft. Other cost items will have slight additional cost depends on the operational flexibility of the schedule, location of active and spare fleet. For example, fuel cost or cabin and cock-bit crew cost are approximately the same in both normal and spare operation considering aircraft and crews are available where needed.

H_i = Block hours of the schedule performed by spare aircraft.

Mathematical Formulation:

The cost of a strategy which has delays and spare aircraft are used during the schedule period, then the operating cost is the sum of the cost of normal operation and the cost of spare operation. In this case the block hours performed by scheduled aircraft are $(H - H_i)$ where H_i is the block hours of the schedule performed by spare aircraft. The spare operations cost due to delays equals hourly cost of spare operations times total block hours performed by spare aircraft (B). Then cost of schedule using strategy i is:

$$C_i = A_i (H - H_i) + B H_i \quad (7)$$

using equation (4) then

$$C_i = J_i \cdot A \cdot (H - H_i) + B \cdot H_i \quad (8)$$

8.4 Derivation of Decision Criteria:

- (a) **Profit criteria** of a strategy (P_i) is defined as the difference between schedule operating revenue minus schedule operating cost for the strategy (i). The **optimum strategy** among a set of strategies based on profit is the strategy which has the highest profit.

$$\text{Profit}_i = \text{Revenue}_i - \text{Cost}_i$$

$$P_i = R_i - C_i \quad (9)$$

Then, equation (9) will be

$$P_i = R(1 - RL_i) - J_i \cdot A \cdot (H - H_i) - B \cdot H_i \quad (9)$$

- (b) **Profit margin criteria** of a strategy (M_i) is defined as the operating profit divided by operating revenue. As in the previous formulation the profit margin decision criteria in PM Optimization is as appears below. The **optimum strategy** based on the profit margin is the strategy which has the maximum profit margin.

$$\text{Profit Margin}_i = \frac{R_i - C_i}{R_i}$$

Then, equation (10) will be

$$M_i = \frac{R(1 - RL_i) - J_i \cdot A \cdot (H - H_i) - B \cdot H_i}{R(1 - RL_i)} \quad (10)$$

8.5 Basis of Optimum Strategy:

As derived in the previous sections the Optimum Strategy is determined by evaluating either the strategy profit criteria (P_i) or the strategy profit margin criteria (M_i).

To implement the above formulation the following Airline Internal Parameters (AIP) are needed;

AIP Notation:

CR = Cost to revenue ratio of no delay operation.

BA = Hourly cost ratio of spare operation to normal operation.

J = The extra operating cost of schedule operations due to increase in ground times (%).

MRL = Maximum revenue loss (%).

Airline internal parameters concern the airlines internal nature of operations, cost and revenue status. The reason for calling them internal parameters is due to the variation from one airline to another. All these parameters are known to the airlines and are used here in the optimization program as interactive input.

Revenue loss for strategy (i) due to delays, (RL_i), is found from the approach which was discussed earlier in section 8.3.1. The RL_i is accumulated for all revenue losses for all flights in the schedule based on the maximum revenue loss (MRL). MRL is found from the survey analysis for different categories of passengers (business passengers and leisure passengers/vacationers). For the purpose of generalization, MRL is used here as an interactive input where the revenue loss function can be changed for sensitivity analysis on revenue loss side.

The CR ratio is required given R_0 "the schedule revenue with all flights on time". The BA ratio is also required which may be based on actual airline data. J and MRL are input to the optimization program in percentage form.

8.6 Conclusion:

A background to the decision criteria is discussed here including mathematical formulation of revenue and cost. Equation (9) describes the profit decision criterion and equation (10) describes the profit margin decision criterion. The Punctuality management optimization approach is drafted in this chapter using Airline Internal Parameters (AIP) and the decision criteria.

In the next chapter, this approach is applied to do the optimization analysis to determine the optimum strategy (ies) and to carry out sensitivity analysis.

CHAPTER (9)

PUNCTUALITY MANAGEMENT STRATEGY OPTIMIZATION ANALYSIS

This chapter applies the mathematical formulation developed in chapter (8) to determine the optimum strategy, perform sensitivity analysis and interpret these results into Airline Punctuality Management Decision variables. Section 9.1 reviews the basis of determining the optimum strategy or strategies. Section 9.2 shows the approach used to find the optimum strategy and discusses the block diagram for the optimization program "OPTIM". Section 9.3 illustrates the output of OPTIM and the sensitivity analysis on the ranges of airline parameters such as revenue to cost ratio and hourly cost of normal (no delays) operation to spare operation and others which will be discussed in more detail. Section 9.4 concludes this chapter with the description of the method of application in the practical airline environment.

9.1 Introduction:

In this research, there are 18 different management strategies related to schedule punctuality. In practice, the airline could have many more management strategies. The key point is how to select the best strategy or set of strategies. Chapter (8) and this chapter discuss the approach and the application of this approach to determine the optimum strategy.

Among the two decision criteria developed in chapter (8); profit decision criterion (P_j) and profit margin decision criterion (M_j), four major airline internal parameters (AIP) are used in the analysis. These parameters are CR, BA, J and MRL which are discussed in details in Chapter 8.

The CR ratio is required as one figure for the entire airline economics. R_0 is the base passengers revenue for all the schedule in case of no delays and no loss in passengers. The BA ratio is an alternative to the actual costing figures which is difficult to get and will represent a specific airline. This approach is more generic and more suitable for sensitivity analysis.

9.2 Finding the Optimum Strategy:

As shown earlier the optimization formula for profit and profit margin decision criteria contains many parameters which have to be evaluated. Therefore, a basic program is developed called "OPTIM" to evaluate Profit decision criteria (P) and profit margin decision criteria (M).

OPTIM program basically takes inputs from airline schedule, schedule simulation results (SKDMOD), passengers attitude survey results and conclusions and from internal airline parameters. Airline schedule information includes total schedule hours, total active aircraft and number of spare aircraft. Schedule simulation (SKDMOD) results are used which includes delays frequency histogram and total spare hours required for operation by a strategy. Passenger impact function and revenue loss function which found from passengers attitude survey are used in OPTIM. Airline internal parameters (AIP) includes CR, BA, J and MRL are used interactively. The output of OPTIM program are the strategies' detailed results including Ground Times, MDAS, calculated loss in revenue, cost, revenue, profit and profit margin decision criteria.

Figure 9-1 illustrates the OPTIM block diagram where OPTIM reads delay histogram resultant from a summary of the schedule simulation flight report output using SKDMOD for a certain strategy. The delay histogram gives more accurate delay statistics compared to the average delay time per day. Therefore, for each strategy simulated by SKDMOD, OPTIM read delays data from the delays summary and the total spare hours utilized for each strategy. **Figure 9-2** shows a sample of delays and summary histogram for a strategy.

From the airline schedule, data such as total scheduled block hours and number of extra aircraft used for the three sets of strategies are given to OPTIM. From the passenger attitude survey findings OPTIM uses the general delay impact function developed in the survey analysis in conjunction with MRL input. **Figure 9-3** shows a sample of the delay impact function.

OPTIM reads four airline internal parameters; the first is the maximum loss in revenue passengers in percentage form. This value represents the maximum value of the loss function (MRL).

The second input variable is cost to revenue ratio of the airline (CR). The third input variable is the ratio of hourly operating cost of spare operations to hourly operating cost of normal operations (BA). The fourth input variable is the percentage extra cost in the operating cost due to additional aircraft in the schedule (J). The extra operating aircraft is due to increasing planned ground time in the schedule.

Figure 9-1 **OPTIM PROGRAM STRUCTURE**
Block Diagram

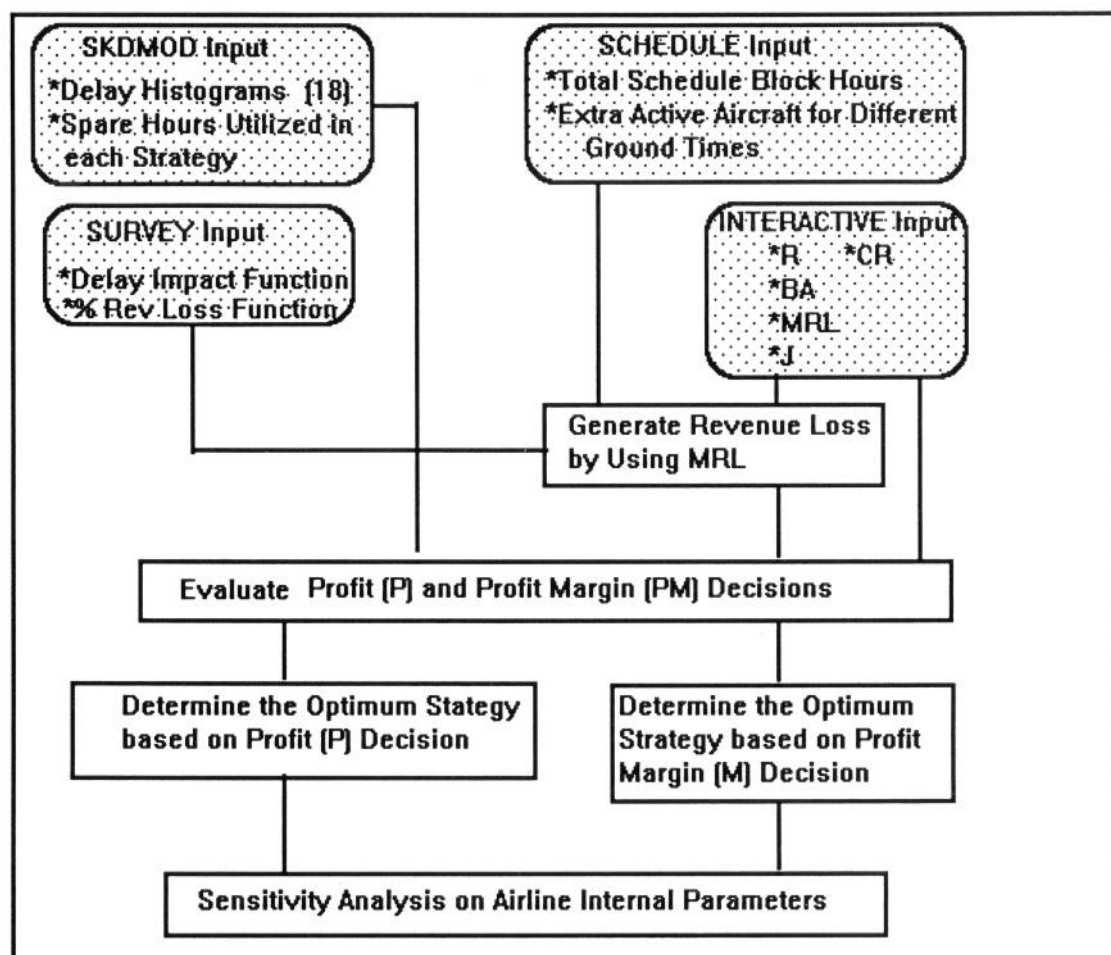


Figure9-2 Sample of Delays Summary Histogram

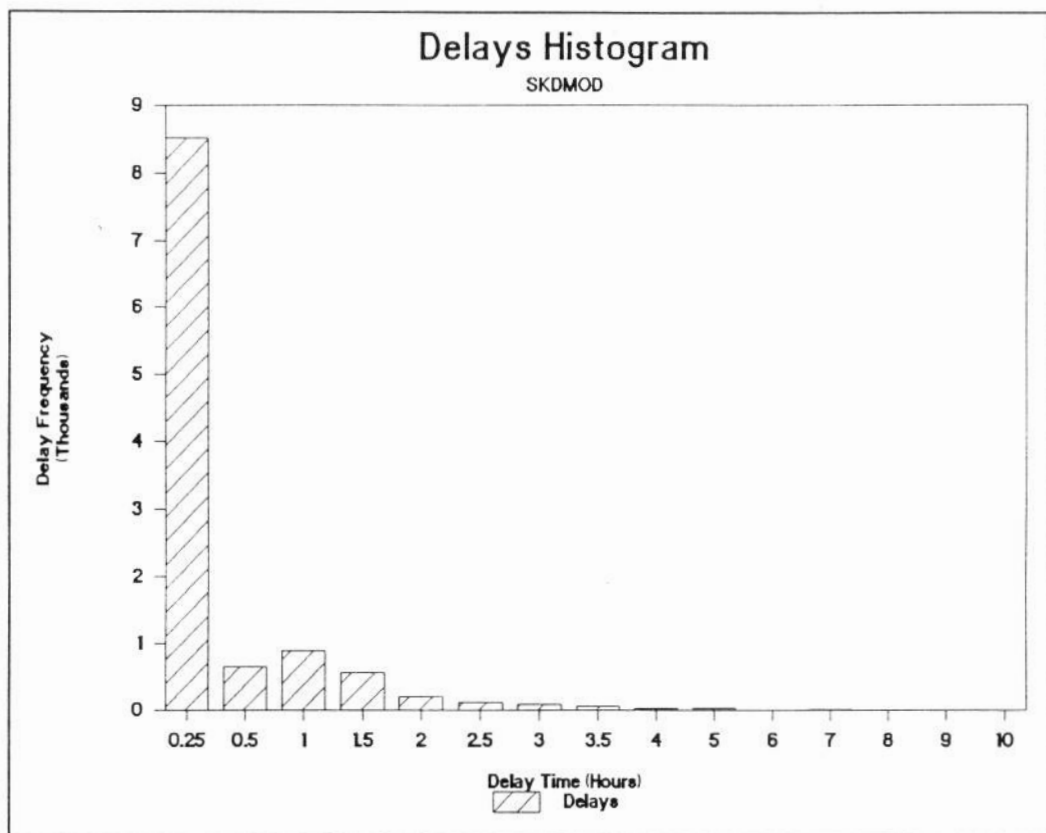
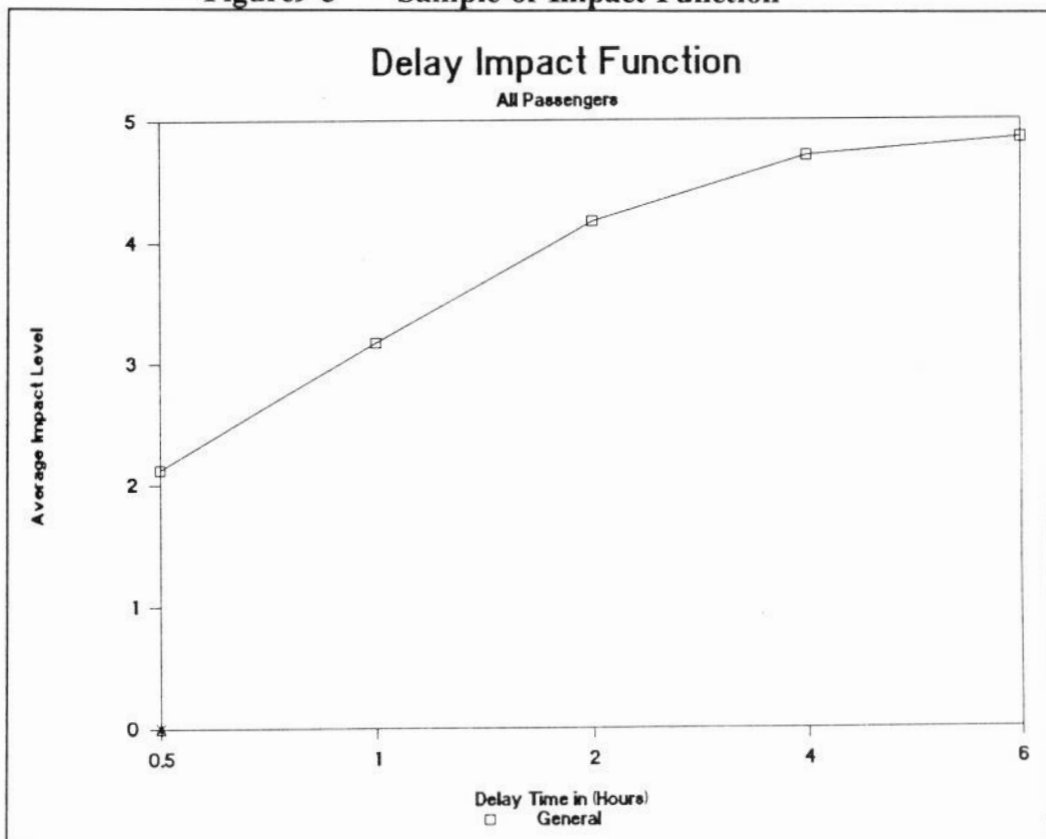


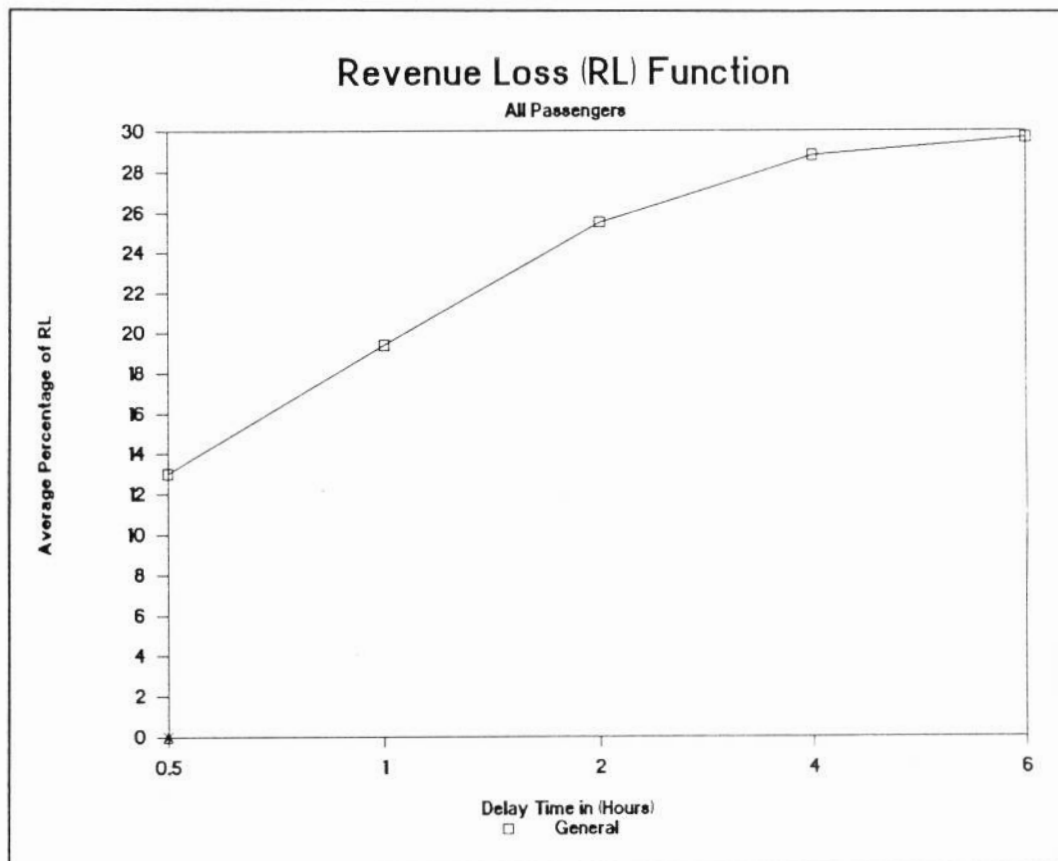
Figure9-3 Sample of Impact Function



The OPTIM program uses the Maximum Revenue Loss (MRL) input by the user, delay histogram and the delay impact function to generate Revenue Loss Function. Delay frequencies which are produced by SKDMOD are transformed to delay histograms which have the same delay time interval used in the delay impact function.

The revenue loss function is generated so for any delay time the expected percentage of passenger revenue loss can be estimated. OPTIM evaluates matrices for profit and profit margin decision criteria. Figure 9-4 shows a sample of revenue loss function which gives the percentages of revenue loss in (%).

Figure 9-4 Sample revenue loss function



9.3 "OPTIM" Output and Sensitivity Analysis:

The optimum strategy or strategies are interpreted in terms of its decision variable to determine the performance of these variables. The decision variables which have been mentioned earlier are ground times (GT) used in developing the schedule plan, maximum delay to assign a spare aircraft (MDAS) and the spare aircraft which is represented by the spare block hours used by the spare aircraft.

When running OPTIM four input are prompted and required including base revenue (R_0) in terms of local/foreign currency, maximum revenue loss (MRL) in terms of percentage, extra cost due to additional spare aircraft (J) in terms of percentages, cost to revenue ratio (CR) in terms of percentages. **Figure 9-5** illustrates the input values to the program.

```
ENTER REVENUE FOR BASE ($) 250000
ENTER MAX LOSS (%) 10
ENTER EXTRA COST DUE TO ADDITIONAL A/C (%) 5
ENTER COST OVER REVENUE (TO OBTAIN A) (%) 50
ENTER B OVER A RATIO (%) 10
```

Figure 9-5 Sample of input format for OPTIM

After executing OPTIM, for each strategy both profit decision criteria and profit margin criteria are determined along with punctuality management decision variables such as GT, MDAS, along with other values for airline internal parameters such as BA, CR, J, and MRL.

Figure 9-6 shows the output of the sample input appears in figure 9-5. It shows that the strategies 1 to 6 (strategy set # 1) are the best among all other 18 strategies because it takes the highest profit and profit margin values. Within those strategies, it is noted that profit and profit margin for strategies 1 to 6 are increasing though the increase is not high. But there is a significant difference between the strategies in set # 1, set # 2 and set # 3. The profit and the profit

margin are different. This is because strategies in set # 1 have 7 aircraft due to the short ground time so part of the cost function is zero which is related to the extra cost for additional aircraft (J) but set # 2 and set # 3 have 8 and 9 aircraft respectively due to longer ground time. This will mean more cost. This is understandable in the case of the strategies sets (groups) but what about within the set.

STR	MDAS	J	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	3.09	125727	242281	116554	48.11
2	2	30	3.18	125833	242053	116720	48.22
3	3	30	3.20	125163	241990	116827	48.28
4	4	30	3.21	125072	241970	116898	48.31
5	5	30	3.21	125039	241970	116930	48.32
6	6	30	3.21	125036	241969	116934	48.33
7	1	40	3.01	131494	242471	110977	45.77
8	2	40	3.06	131375	242359	110984	45.78
9	3	40	3.08	131314	242310	110996	45.80
10	4	40	3.08	131280	242289	111009	45.82
11	5	40	3.09	131265	242286	111021	45.82
12	6	40	3.09	131265	242287	111021	45.82
13	1	50	2.94	137500	242593	105093	43.32
14	2	50	2.99	137500	242527	105027	43.31
15	3	50	2.99	137500	242517	105017	43.30
16	4	50	2.99	137500	242509	105009	43.30
17	5	50	2.99	137500	242513	105013	43.30
18	6	50	3.00	137500	242508	105008	43.30

Figure 9-6 Sample output of OPTIM program

It is also noticeable that the profit and profit margin in the first set are higher as MDAS (Maximum Delay to Assign Spare aircraft) increases because when MDAS increases the spare utilization will be lower and the revenue loss will increase. When spare utilization decreases then the value of the second part of the cost equation is lower and on the revenue side the revenue loss will be higher because the loss will increase for higher MDAS.

Strategies 4 to 6 are similar in the profit and profit margin. This means theoretically that strategy # 6 is the best strategy but as illustrated, there is no big difference between the strategies from 4 to 6. Practically speaking, an airline will prefer strategy 4 because it will have lower impact on passengers especially if the airline is a service oriented not profit making oriented only.

This leads to many questions such as what is the optimum strategy if the maximum revenue loss is higher than 10% (as in the sample output) and what about if the extra cost due to additional aircraft is not a fraction of the cost but it is a double of the cost. Similarly, what is the optimum strategy if the airline is making profit or making loss and what about if the hourly cost of the spare operation is a fraction of the normal hourly cost or double the cost. This analysis is done using OPTIM program using the following ranges of parameters which will reflect the sensitivity analysis for those input parameters.

OPTIM Parameters Ranges:

OPTIM parameters are R_o , MRL, J, CR and BA. The minimum and maximum values below represent the range of analysis. The base schedule revenue for all flights performing on time operation is assumed to be \$250000. This value could be lower or higher, it would not change the optimum strategy. Maximum revenue loss is selected to be in between 10% and 40% covering all revenue loss values found from the attitude survey (general passengers, vacationers and business passengers). The cost of extra active aircraft ranges between a fraction of the total operation cost (5%) to more than double the cost of operations (110%). The cost to revenue ratio covers two types of airline economics which are profit making (the ratio is 50%) and loss making (the ratio is 150%). Hourly cost of spare operation to normal operations is analyzed in the range of 10% , which means the spare block hour cost a fraction of the normal block hour , to 210% which means the spare block hour cost is higher (double) the normal block hour cost. Ranges of analysis are selected as follows:

R_o	:	250000	
		<u>Minimum</u>	<u>Maximum</u>
MRL	:	10%	40%
J	:	5%	110%
CR	:	50%	150%
BA	:	10%	210%

Then to find out the possible change in the optimum strategy if those parameters changed it is necessary to cover all combinations of the those parameters ranges. 16 combinations are developed between the minimum and maximum of the ranges. Using OPTIM the results are analyzed. Some selected outputs are attached in the following figures 9-7 to 9-15. In these figures the words

minimum and maximum are used in discussing the results which are the same maximum and minimum values shown in the above ranges. In other words, when it reads as the minimum values of MRL, J, CR and BA as in figure 9-7 it means MRL equals 10% (low percentage revenue loss function), J equals 5% (the hourly cost of the normal operation increased by 5% due to the extra active aircraft in the schedule), CR equals 50% (the airline is a profit making) and BA equals 10% (the hourly cost of the spare operation is a fraction of the normal hourly cost).

ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50								
ENTER B/A RATIO IN % 10								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MRG
1	1	30	3.09	125727	242281	116554	48.11	
2	2	30	3.18	125333	242053	116720	48.22	
3	3	30	3.20	125163	241990	116827	48.28	
4	4	30	3.21	125072	241970	116898	48.31	
5	5	30	3.21	125039	241970	116931	48.32	
6	6	30	3.21	125036	241969	116934	48.33	
7	1	40	3.01	131494	242471	110977	45.77	
8	2	40	3.06	131375	242359	110984	45.79	
9	3	40	3.08	131314	242310	110996	45.81	
10	4	40	3.08	131280	242289	111009	45.82	
11	5	40	3.09	131265	242286	111021	45.82	
12	6	40	3.09	131265	242287	111021	45.82	
13	1	50	2.96	137500	242593	105093	43.32	
14	2	50	2.99	137500	242527	105027	43.31	
15	3	50	2.99	137500	242517	105017	43.30	
16	4	50	3.00	137500	242509	105009	43.30	
17	5	50	2.99	137500	242513	105013	43.30	
18	6	50	3.00	137500	242508	105008	43.30	
ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50								
ENTER B/A RATIO IN % 210								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MRG
1	1	30	3.09	140262	242281	102020	42.11	
2	2	30	3.18	131991	242053	110062	45.47	
3	3	30	3.20	128421	241990	113569	46.93	
4	4	30	3.21	126515	241970	115455	47.71	
5	5	30	3.21	125811	241970	116159	48.01	
6	6	30	3.21	125751	241969	116219	48.03	
7	1	40	3.01	141257	242471	101215	41.74	
8	2	40	3.06	136375	242359	105984	43.73	
9	3	40	3.08	133891	242310	108420	44.74	
10	4	40	3.08	132463	242289	109826	45.33	
11	5	40	3.09	131878	242286	110408	45.57	
12	6	40	3.09	131878	242287	110409	45.57	
13	1	50	2.96	144687	242593	97906	40.36	
14	2	50	2.99	140745	242527	101781	41.97	
15	3	50	2.99	138767	242517	103749	42.78	
16	4	50	3.00	138356	242509	104153	42.95	
17	5	50	2.99	137861	242513	104652	43.15	
18	6	50	3.00	137861	242508	104648	43.15	

Figure 9-7 OPTIM output for input ranges

Figure 9-7 illustrates the results for the minimum values of input ranges (MRL, J, CR and BA), strategies 4,5 and 6 have similar profit and profit margin but strategy 6 is the optimum (the profit margin is 48.32%). Similarly when BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but also strategy 6 is the optimum (the profit margin is 48.03%). The optimum strategy has lower profit margin value in the second run when BA is at its maximum value compared to the first run when BA is at its minimum value.

ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150								
ENTER B/A RATIO IN % 10								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MGR
1	1	30	3.09	377180	242281	-134899	-55.68	
2	2	30	3.18	375999	242053	-133946	-55.34	
3	3	30	3.20	375489	241990	-133499	-55.17	
4	4	30	3.21	375216	241970	-133247	-55.07	
5	5	30	3.21	375116	241970	-133146	-55.03	
6	6	30	3.21	375107	241969	-133138	-55.02	
7	1	40	3.01	394482	242471	-152011	-62.69	
8	2	40	3.06	394125	242359	-151766	-62.62	
9	3	40	3.08	393943	242310	-151633	-62.58	
10	4	40	3.08	393839	242289	-151550	-62.55	
11	5	40	3.09	393796	242286	-151510	-62.53	
12	6	40	3.09	393796	242287	-151509	-62.53	
13	1	50	2.96	412500	242593	-169907	-70.04	
14	2	50	2.99	412500	242527	-169973	-70.08	
15	3	50	2.99	412500	242517	-169983	-70.09	
16	4	50	3.00	412500	242509	-169991	-70.10	
17	5	50	2.99	412500	242513	-169987	-70.09	
18	6	50	3.00	412500	242508	-169992	-70.10	
ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150								
ENTER B/A RATIO IN % 210								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MGR
1	1	30	3.09	420785	242231	-178503	-73.68	
2	2	30	3.18	395973	242053	-153920	-63.59	
3	3	30	3.20	385263	241990	-143273	-59.21	
4	4	30	3.21	379545	241970	-137575	-56.86	
5	5	30	3.21	377433	241970	-135463	-55.98	
6	6	30	3.21	377253	241969	-135283	-55.91	
7	1	40	3.01	423770	242471	-181299	-74.77	
8	2	40	3.06	409124	242359	-166765	-68.81	
9	3	40	3.08	401672	242310	-159362	-65.77	
10	4	40	3.08	397388	242289	-155099	-64.01	
11	5	40	3.09	395634	242286	-153348	-63.29	
12	6	40	3.09	395634	242287	-153347	-63.29	
13	1	50	2.96	434061	242593	-191468	-78.93	
14	2	50	2.99	422236	242527	-179709	-74.10	
15	3	50	2.99	416302	242517	-173786	-71.66	
16	4	50	3.00	415069	242509	-172560	-71.16	
17	5	50	2.99	413582	242513	-171069	-70.54	
18	6	50	3.00	413582	242508	-171074	-70.54	

Figure 9-8 OPTIM output for input ranges

Figure 9-8 shows the OPTIM results for the minimum values MRL, J and BA, and maximum value of CR, the profit and profit margin are negative. Strategies 4,5 and 6 have similar profit and profit margin but strategy 6 is the optimum (the profit margin is -55.03%). Similarly when BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but also strategy 6 is the optimum (the profit margin is -55.91%). This means that an increase in the BA ratio will decrease the profit margin.

ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50								
ENTER B/A RATIO IN % 10								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MGR
1	1	30	3.09	25727	242281	116554	48.11	
2	2	30	3.18	125333	242053	116720	48.22	
3	3	30	3.20	125163	241990	116827	48.28	
4	4	30	3.21	125072	241970	116898	48.31	
5	5	30	3.21	125039	241970	116931	48.32	
6	6	30	3.21	125036	241969	116934	48.33	
7	1	40	3.01	257619	242471	-15147	-6.25	
8	2	40	3.06	260000	242359	-17641	-7.28	
9	3	40	3.08	261212	242310	-18902	-7.80	
10	4	40	3.08	261908	242289	-19620	-8.10	
11	5	40	3.09	262194	242286	-19907	-8.22	
12	6	40	3.09	262194	242287	-19907	-8.22	
13	1	50	2.96	392454	242593	-149861	-61.77	
14	2	50	2.99	396593	242527	-154066	-63.53	
15	3	50	2.99	398669	242517	-156152	-64.39	
16	4	50	3.00	399101	242509	-156592	-64.57	
17	5	50	2.99	399621	242513	-157109	-64.78	
18	6	50	3.00	399621	242508	-157113	-64.79	
ENTER REVENUE FOR BASE 250000								
ENTER MAX LOSS IN (%) 10								
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110								
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50								
ENTER B/A RATIO IN % 210								
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MGR
1	1	30	3.09	140262	242281	102020	42.11	
2	2	30	3.18	131991	242053	110062	45.47	
3	3	30	3.20	128421	241990	113569	46.93	
4	4	30	3.21	126515	241970	115455	47.71	
5	5	30	3.21	125811	241970	116159	48.01	
6	6	30	3.21	125751	241969	116219	48.03	
7	1	40	3.01	267381	242471	-24910	-10.27	
8	2	40	3.06	265000	242359	-22641	-9.34	
9	3	40	3.08	263788	242310	-21478	-8.86	
10	4	40	3.08	263092	242289	-20803	-8.59	
11	5	40	3.09	262806	242286	-20520	-8.47	
12	6	40	3.09	262806	242287	-20520	-8.47	
13	1	50	2.96	399641	242593	-157048	-64.74	
14	2	50	2.99	399838	242527	-157311	-64.86	
15	3	50	2.99	399937	242517	-157420	-64.91	
16	4	50	3.00	399957	242509	-157448	-64.92	
17	5	50	2.99	399982	242513	-157469	-64.93	
18	6	50	3.00	399982	242508	-157474	-64.94	

Figure 9-9 OPTIM output for input ranges

Figure 9-9 illustrates the OPTIM results for the minimum values MRL, CR and BA, and maximum value of J, strategies 1 to 6 profit and profit margin are positive and strategies 7-18 are negative. Strategies 4, 5 and 6 have similar profit and profit margin but strategy 6 is the optimum (the profit margin is 48.33%). Similarly when BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but also strategy 6 is the optimum (the profit margin is 48.03%). This means that an increase in the BA ratio will decrease the profit margin.


```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 10
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
ENTER B/A RATIO IN % 10
  STR MDAS  GT  LOSS  COST REVENUE  PROFIT PR MRG
    1      1  30   3.09  377180  242281 -134899 -55.68
    2      2  30   3.18  375999  242053 -133946 -55.34
    3      3  30   3.20  375489  241990 -133499 -55.17
    4      4  30   3.21  375216  241970 -133247 -55.07
    5      5  30   3.21  375116  241970 -133146 -55.03
    6      6  30   3.21  375107  241969 -133138 -55.02
    7      1  40   3.01  772856  242471 -530385 -218.74
    8      2  40   3.06  780000  242359 -537642 -221.84
    9      3  40   3.08  783635  242310 -541325 -223.40
   10      4  40   3.08  785725  242289 -543437 -224.29
   11      5  40   3.09  786581  242286 -544295 -224.65
   12      6  40   3.09  786581  242287 -544294 -224.65
   13      1  50   2.96 1177361  242593 -934768 -385.32
   14      2  50   2.99 1189778  242527 -947251 -390.58
   15      3  50   2.99 1196007  242517 -953491 -393.16
   16      4  50   3.00 1197303  242509 -954794 -393.71
   17      5  50   2.99 1198864  242513 -956351 -394.35
   18      6  50   3.00 1198864  242508 -956356 -394.36

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 10
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
ENTER B/A RATIO IN % 210
  STR MDAS  GT  LOSS  COST REVENUE  PROFIT PR MRG
    1      1  30   3.09  420785  242281 -178503 -73.68
    2      2  30   3.18  395973  242053 -153920 -63.59
    3      3  30   3.20  385263  241990 -143273 -59.21
    4      4  30   3.21  379545  241970 -137575 -56.86
    5      5  30   3.21  377433  241970 -135463 -55.98
    6      6  30   3.21  377253  241969 -135283 -55.91
    7      1  40   3.01  802144  242471 -559673 -230.82
    8      2  40   3.06  795000  242359 -552641 -228.03
    9      3  40   3.08  791364  242310 -549054 -226.59
   10      4  40   3.08  789275  242289 -546986 -225.76
   11      5  40   3.09  788419  242286 -546133 -225.41
   12      6  40   3.09  788419  242287 -546132 -225.41
   13      1  50   2.96 1198922  242593 -956329 -394.21
   14      2  50   2.99 1199513  242527 -956987 -394.59
   15      3  50   2.99 1199810  242517 -957293 -394.73
   16      4  50   3.00 1199872  242509 -957363 -394.77
   17      5  50   2.99 1199946  242513 -957433 -394.80
   18      6  50   3.00 1199946  242508 -957438 -394.81

```

Figure 9-10 OPTIM output for input ranges

Figure 9-10 shows the OPTIM results for the minimum values MRL and BA, and the maximum value of J and CR, strategies 1 to 18 profit and profit margin are negative. Strategies 5 and 6 have similar profit and profit margin but strategy 6 is the optimum strategy (the profit margin is -55.02%). Similarly when BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but also strategy 6 is the optimum (the profit margin is -55.91%). This means that an increase in the BA ratio will decrease the profit margin.

```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 40
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50
ENTER B/A RATIO IN % 10

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	125727	219125	93398	42.62
2	2	30	12.72	125333	218212	92879	42.56
3	3	30	12.82	125163	217960	92797	42.58
4	4	30	12.85	125072	217880	92807	42.60
5	5	30	12.85	125039	217878	92840	42.61
6	6	30	12.85	125036	217878	92842	42.61
7	1	40	12.05	131494	219885	88391	40.20
8	2	40	12.23	131375	219435	88060	40.13
9	3	40	12.30	131314	219241	87926	40.10
10	4	40	12.34	131280	219156	87876	40.10
11	5	40	12.34	131265	219145	87880	40.10
12	6	40	12.34	131265	219147	87882	40.10
13	1	50	11.85	137500	220373	82873	37.61
14	2	50	11.96	137500	220106	82606	37.53
15	3	50	11.97	137500	220067	82567	37.52
16	4	50	11.99	137500	220036	82536	37.51
17	5	50	11.98	137500	220051	82551	37.51
18	6	50	11.99	137500	220033	82533	37.51

```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 40
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50
ENTER B/A RATIO IN % 210

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	140262	219125	78863	35.99
2	2	30	12.72	131991	218212	86221	39.51
3	3	30	12.82	128421	217960	89539	41.08
4	4	30	12.85	126515	217880	91365	41.93
5	5	30	12.85	125811	217878	92068	42.26
6	6	30	12.85	125751	217878	92127	42.28
7	1	40	12.05	141257	219885	78629	35.76
8	2	40	12.23	136375	219435	83060	37.85
9	3	40	12.30	133891	219241	85350	38.93
10	4	40	12.34	132463	219156	86693	39.56
11	5	40	12.34	131878	219145	87267	39.82
12	6	40	12.34	131878	219147	87269	39.82
13	1	50	11.85	144687	220373	75686	34.34
14	2	50	11.96	140745	220106	79361	36.06
15	3	50	11.97	138767	220067	81300	36.94
16	4	50	11.99	138356	220036	81680	37.12
17	5	50	11.98	137861	220051	82190	37.35
18	6	50	11.99	137861	220033	82173	37.35

Figure 9-11 OPTIM output for input ranges

Figure 9-11 illustrates the OPTIM output for the maximum value of MRL and the minimum values of J, CR and BA, all strategies profit and profit margin are positive. Strategies 4,5 and 6 have similar profit and profit margin but strategy 1 is the optimum (the profit margin is 42.62%). Similarly when the BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but also strategy 6 is the optimum (the profit margin is 42.28%).


```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 40
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
ENTER B/A RATIO IN % 10

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	377180	219125	-158055	-72.13
2	2	30	12.72	375999	218212	-157787	-72.31
3	3	30	12.82	375489	217960	-157529	-72.27
4	4	30	12.85	375216	217880	-157337	-72.21
5	5	30	12.85	375116	217878	-157237	-72.17
6	6	30	12.85	375107	217878	-157230	-72.16
7	1	40	12.05	394482	219885	-174597	-79.40
8	2	40	12.23	394125	219435	-174690	-79.61
9	3	40	12.30	393943	219241	-174702	-79.69
10	4	40	12.34	393839	219156	-174683	-79.71
11	5	40	12.34	393796	219145	-174651	-79.70
12	6	40	12.34	393796	219147	-174649	-79.69
13	1	50	11.85	412500	220373	-192127	-87.18
14	2	50	11.96	412500	220106	-192394	-87.41
15	3	50	11.97	412500	220067	-192433	-87.44
16	4	50	11.99	412500	220036	-192464	-87.47
17	5	50	11.98	412500	220051	-192449	-87.46
18	6	50	11.99	412500	220033	-192467	-87.47

```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 40
ENTER EXTRA COST DUE TO ADDNL A/C (%) 5
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
ENTER B/A RATIO IN % 210

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	420785	219125	-201660	-92.03
2	2	30	12.72	395973	218212	-177761	-81.46
3	3	30	12.82	385263	217960	-167303	-76.76
4	4	30	12.85	379545	217880	-161665	-74.20
5	5	30	12.85	377433	217878	-159554	-73.23
6	6	30	12.85	377253	217878	-159375	-73.15
7	1	40	12.05	423770	219885	-203885	-92.72
8	2	40	12.23	409124	219435	-189689	-86.44
9	3	40	12.30	401672	219241	-182431	-83.21
10	4	40	12.34	397388	219156	-178232	-81.33
11	5	40	12.34	395634	219145	-176489	-80.54
12	6	40	12.34	395634	219147	-176487	-80.53
13	1	50	11.85	434061	220373	-213688	-96.97
14	2	50	11.96	422236	220106	-202129	-91.83
15	3	50	11.97	416302	220067	-196235	-89.17
16	4	50	11.99	415069	220036	-195033	-88.64
17	5	50	11.98	413582	220051	-193531	-87.95
18	6	50	11.99	413582	220033	-193549	-87.96

Figure 9-12 OPTIM output for input ranges

Figure 9-12 shows the OPTIM output for the maximum value of MRL and CR, and the minimum values of J and BA, strategies 1 to 18 profit and profit margin are negative. Strategies 5 and 6 have similar profit and profit margin but strategy 6 is the optimum strategy (the profit margin is -72.16%). Similarly when the BA ratio has the maximum value strategy 6 is the optimum strategy in terms of profit and profit margin (the profit margin is -73.15%).

ENTER REVENUE FOR BASE 250000							
ENTER MAX LOSS IN (%) 40							
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110							
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50							
ENTER B/A RATIO IN % 10							
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	125727	219125	93398	42.62
2	2	30	12.72	125333	218212	92879	42.56
3	3	30	12.82	125163	217960	92797	42.58
4	4	30	12.85	125072	217880	92807	42.60
5	5	30	12.85	125039	217878	92840	42.61
6	6	30	12.85	125036	217878	92842	42.61
7	1	40	12.05	257619	219885	-37733	-17.16
8	2	40	12.23	260000	219435	-40565	-18.49
9	3	40	12.30	261212	219241	-41971	-19.14
10	4	40	12.34	261908	219156	-42753	-19.51
11	5	40	12.34	262194	219145	-43049	-19.64
12	6	40	12.34	262194	219147	-43046	-19.64
13	1	50	11.85	392454	220373	-172081	-78.09
14	2	50	11.96	396593	220106	-176486	-80.18
15	3	50	11.97	398669	220067	-178602	-81.16
16	4	50	11.99	399101	220036	-179064	-81.38
17	5	50	11.98	399621	220051	-179571	-81.60
18	6	50	11.99	399621	220033	-179588	-81.62
ENTER REVENUE FOR BASE 250000							
ENTER MAX LOSS IN (%) 40							
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110							
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50							
ENTER B/A RATIO IN % 210							
STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	12.35	140262	219125	78863	35.99
2	2	30	12.72	131991	218212	86221	39.51
3	3	30	12.82	123421	217960	89539	41.08
4	4	30	12.85	126515	217880	91365	41.93
5	5	30	12.85	125811	217878	92068	42.26
6	6	30	12.85	125751	217878	92127	42.28
7	1	40	12.05	267381	219885	-47496	-21.60
8	2	40	12.23	265000	219435	-45565	-20.76
9	3	40	12.30	263788	219241	-44547	-20.32
10	4	40	12.34	263092	219156	-43936	-20.05
11	5	40	12.34	262806	219145	-43661	-19.92
12	6	40	12.34	262806	219147	-43659	-19.92
13	1	50	11.85	399641	220373	-179268	-81.35
14	2	50	11.96	399838	220106	-179731	-81.66
15	3	50	11.97	399937	220067	-179870	-81.73
16	4	50	11.99	399957	220036	-179921	-81.77
17	5	50	11.98	399982	220051	-179931	-81.77
18	6	50	11.99	399982	220033	-179949	-81.78

Figure 9-13 OPTIM output for input ranges

Figure 9-13 illustrates the OPTIM results for maximum value of MRL and J, and the minimum values CR and BA, strategies 1 to 6 profit and profit margin are positive and strategies 7-18 are negative. Strategies 1,4, 5 and 6 have similar profit and profit margin but strategy 1 is the optimum (the profit margin is 42.62%). When BA ratio has the maximum value strategy 5 and 6 are the highest in terms of profit and profit margin but strategy 6 is the optimum (the profit margin is 42.28%).

ENTER REVENUE FOR BASE 250000
 ENTER MAX LOSS IN (%) 40
 ENTER EXTRA COST DUE TO ADDNL A/C (%) 110
 ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
 ENTER B/A RATIO IN % 10

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MRG
1	1	30	12.35	377180	219125	-158055	-72.13	
2	2	30	12.72	375999	218212	-157787	-72.31	
3	3	30	12.82	375489	217960	-157529	-72.27	
4	4	30	12.85	375216	217880	-157337	-72.21	
5	5	30	12.85	375116	217878	-157237	-72.17	
6	6	30	12.85	375107	217878	-157230	-72.16	
7	1	40	12.05	772856	219835	-552971	-251.48	
8	2	40	12.23	780000	219435	-560565	-255.46	
9	3	40	12.30	783635	219241	-564395	-257.43	
10	4	40	12.34	785725	219156	-566570	-258.52	
11	5	40	12.34	786581	219145	-567436	-258.93	
12	6	40	12.34	786581	219147	-567434	-258.93	
13	1	50	11.85	1177361	220373	-956989	-434.26	
14	2	50	11.96	1189778	220106	-969671	-440.55	
15	3	50	11.97	1196007	220067	-975940	-443.47	
16	4	50	11.99	1197303	220036	-977266	-444.14	
17	5	50	11.98	1198864	220051	-978813	-444.81	
18	6	50	11.99	1198864	220033	-978831	-444.86	

ENTER REVENUE FOR BASE 250000
 ENTER MAX LOSS IN (%) 40
 ENTER EXTRA COST DUE TO ADDNL A/C (%) 110
 ENTER COST OVER REVENUE (TO OBTAIN A) IN % 150
 ENTER B/A RATIO IN % 210

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR	MRG
1	1	30	12.35	420785	219125	-201660	-92.03	
2	2	30	12.72	395973	218212	-177761	-81.56	
3	3	30	12.82	385263	217960	-167303	-76.76	
4	4	30	12.85	379545	217880	-161665	-74.20	
5	5	30	12.85	377433	217878	-159554	-73.23	
6	6	30	12.85	377253	217878	-159375	-73.15	
7	1	40	12.05	802144	219885	-582259	-264.80	
8	2	40	12.23	795000	219435	-575565	-262.29	
9	3	40	12.30	791364	219241	-572124	-260.96	
10	4	40	12.34	789275	219156	-570119	-260.14	
11	5	40	12.34	788419	219145	-569274	-259.77	
12	6	40	12.34	788419	219147	-569272	-259.77	
13	1	50	11.85	1198922	220373	-978549	-444.04	
14	2	50	11.96	1199513	220106	-979407	-444.97	
15	3	50	11.97	1199810	220067	-979743	-445.20	
16	4	50	11.99	1199872	220036	-979835	-445.31	
17	5	50	11.98	1199946	220051	-979895	-445.30	
18	6	50	11.99	1199946	220033	-979913	-445.35	

Figure 9-14 OPTIM output for input ranges

Figure 9-14 shows the OPTIM results for the maximum value of MRL, J and CR, and the minimum values of BA, strategies 1 to 18 profit and profit margin are negative. Strategies 1, 5 and 6 have similar profit and profit margin but strategy 1 is the optimum strategy (the profit margin is -72.16%). When BA ratio has the maximum value strategies 5 and 6 are similar in terms of profit and profit margin but strategy 6 is the optimum strategy (the profit margin is -73.15%).

```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 60
ENTER EXTRA COST DUE TO ADDNL A/C (%) 110
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50
ENTER B/A RATIO IN % 210

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	18.53	140262	203687	63426	31.14
2	2	30	19.07	131991	202318	70327	34.76
3	3	30	19.22	128421	201939	73518	36.41
4	4	30	19.27	126515	201819	75304	37.31
5	5	30	19.27	125811	201818	76007	37.66
6	6	30	19.27	125751	201816	76065	37.69
7	1	40	18.07	267381	204828	-62553	-30.54
8	2	40	18.34	265000	204153	-60847	-29.80
9	3	40	18.46	263788	203861	-59927	-29.40
10	4	40	18.51	263092	203734	-59358	-29.13
11	5	40	18.51	262806	203717	-59089	-29.01
12	6	40	18.51	262806	203721	-59086	-29.00
13	1	50	17.78	399641	205559	-194082	-94.42
14	2	50	17.94	399838	205159	-194678	-94.89
15	3	50	17.96	399937	205101	-194836	-95.00
16	4	50	17.98	399957	205055	-194903	-95.05
17	5	50	17.97	399982	205076	-194906	-95.04
18	6	50	17.98	399982	205050	-194932	-95.07

```

ENTER REVENUE FOR BASE 250000
ENTER MAX LOSS IN (%) 10
ENTER EXTRA COST DUE TO ADDNL A/C (%) (2)
ENTER COST OVER REVENUE (TO OBTAIN A) IN % 50
ENTER B/A RATIO IN % 10

```

STR	MDAS	GT	LOSS	COST	REVENUE	PROFIT	PR MRG
1	1	30	3.09	125727	242281	116554	48.11
2	2	30	3.18	125333	242053	116720	48.22
3	3	30	3.20	125163	241990	116827	48.28
4	4	30	3.21	125072	241970	116898	48.31
5	5	30	3.21	125039	241970	116931	48.32
6	6	30	3.21	125036	241969	116934	48.33
7	1	40	3.01	127891	242471	114581	47.26
8	2	40	3.06	127700	242359	114659	47.31
9	3	40	3.08	127603	242310	114707	47.34
10	4	40	3.08	127547	242289	114742	47.36
11	5	40	3.09	127525	242286	114762	47.37
12	6	40	3.09	127525	242287	114762	47.37
13	1	50	2.96	130216	242593	112378	46.32
14	2	50	2.99	130097	242527	112429	46.36
15	3	50	2.99	130038	242517	112479	46.38
16	4	50	3.00	130026	242509	112483	46.38
17	5	50	2.99	130011	242513	112502	46.39
18	6	50	3.00	130011	242508	112498	46.39

Figure 9-15 OPTIM output for input ranges

In the above figure 8-15 MRL is very high (60%) to check the sensitivity of the optimum strategy, for the maximum value of J and BA, and the minimum values of CR, strategies 1-6 are positive and strategies 7-18 are negative in both profit and profit margin criteria. Strategies 5 and 6 have similar profit and profit margin but strategy 6 is the optimum (the profit margin is 37.69%).

The second part of figure 8-15 illustrates the optimum strategy if minimum range of J is very low (2%), with all minimum ranges for all parameters (MRL,

CR and BA), strategies 4, 5 and 6 are similar in terms of profit and profit margin but strategy 6 is the optimum (the profit margin is 48.33%).

9.4 Conclusions:

Strategy set # 1 (strategies 1 to 6) in all cases of minimum and maximum parameters ranges that are shown in the previous section gives the **best** profit and profit margin results. All strategy sets are **not profitable** when the airline is a loss making (maximum CR) regardless of BA, MRL and J values.

Strategy set # 1 which has the minimum ground time (30 minutes) and the minimum number of active operational fleet (7 aircraft) gives always a **profitable** result (positive profit and profit margin) when the airline is profit making (minimum CR) regardless of BA, MRL and J values.

Strategy sets # 2 and # 3 (strategies 7 to 18) gives a **profitable** result when the airline is profit making and the spare hour cost a fraction of the normal hourly cost (CR and BA is minimum). They also produce a profitable results when the airline is profit making and the spare hour cost is higher than the normal hourly cost (CR is at its minimum and BA at its maximum) except when the cost of the extra active aircraft is high (maximum J) where sets # 2 and # 3 are **not profitable**.

Strategies 4, 5 and 6 of set # 1 are similar which give the **best** profit and profit margin results but the **optimum** strategy in all cases is strategy 6 except in two cases where strategy 1 is the optimum. The first case when using the high revenue loss function, the airline is a profit making, the normal hourly cost is increased by a fraction due to extra active aircraft and the spare hour cost is a fraction of the normal hour cost. (maximum MRL, and minimum J, CR and BA). The second case when using the high revenue loss function, the normal hourly is increased to the double due to extra active aircraft, the airline is profit making and the spare hour cost is a fraction of the normal hourly cost (maximum MRL and J, and minimum CR and BA)

Strategies 1, 4, 5 and 6 are the strategies which have 30 minutes ground time, one, four, five and six hours MDAS respectively. Strategy 1 has maximum utilization of spare aircraft and strategy 6 has minimum utilization of spare aircraft.

Figure 9-16 and figure 9-17 summarize the profit margin for all strategies using the low percentage revenue loss and the airline is a profit making (minimum CR and the minimum MRL). In these graphs, ranges of these strategies are represented by four characters corresponding to the four airline parameters. These parameters are MRL, J, CR and BA. Each is represented either by maximum (x) or minimum (m) of the range in the same order.

Figure 9-16 shows all the 18 strategies for a profit making airline and using low percentage revenue loss function. There are four graphs which represent four cases. The first case when the normal hourly cost is increased by a fraction and the spare block hourly cost is a fraction of the normal hourly cost (mmmm) gives a profitable results for all the 18 strategies. The second case when the normal hourly cost is increased by a fraction and the spare block hourly cost is higher than the normal hourly cost (mmm \times) gives also a profitable results for all 18 strategies. The third case when the normal hourly cost is doubled due to extra active aircraft and the spare block hourly cost is a fraction of the normal hourly cost (mxmm) gives a profitable results for the first six strategies and a loss results for the second and third sets of strategies. Similarly the fourth case when the normal hourly cost is doubled due to extra active aircraft and the spare block hourly cost is higher than the normal hourly cost (mxm \times) gives profitable results for the first six strategies and a loss results for the second and third sets of strategies

Figure 9-18 focuses on strategy set #1. It shows all the six strategies (1 to 6) for profit making airline and using low percentage revenue loss function. There are four graphs which represent four cases although it appears to be as two graphs because the normal hourly cost is not affected with J parameter . J equals 1 because in this schedule there is no extra active aircraft. So graph mmmm and graph mmm \times will discussed. For the same conditions; when using low revenue loss function and the airline is profit making then strategies 1 to 6 gives higher profit margin (48%) when the spare hourly cost is a fraction of the normal hourly cost, compared to (42%-47%) when the spare hourly cost is higher than the normal hourly cost.

Figure 9-18 similarly shows all the 18 strategies for profit making airline but using high percentage revenue loss function (minimum CR and maximum MRL). There are four graphs which are similar to the graphs discussed in figure 9-16. **Figure 9-20** shows the behaviour of the first six strategies for profit making airline and using high percentage revenue loss function. For the same conditions; strategies 1 to 6 gives higher profit margin (42.5%) when the spare hourly cost is a fraction of the normal hourly cost, compared to (36%-42%) when the spare hourly cost is higher than the normal hourly cost..

Figure9-16 Strategy Profit Margin

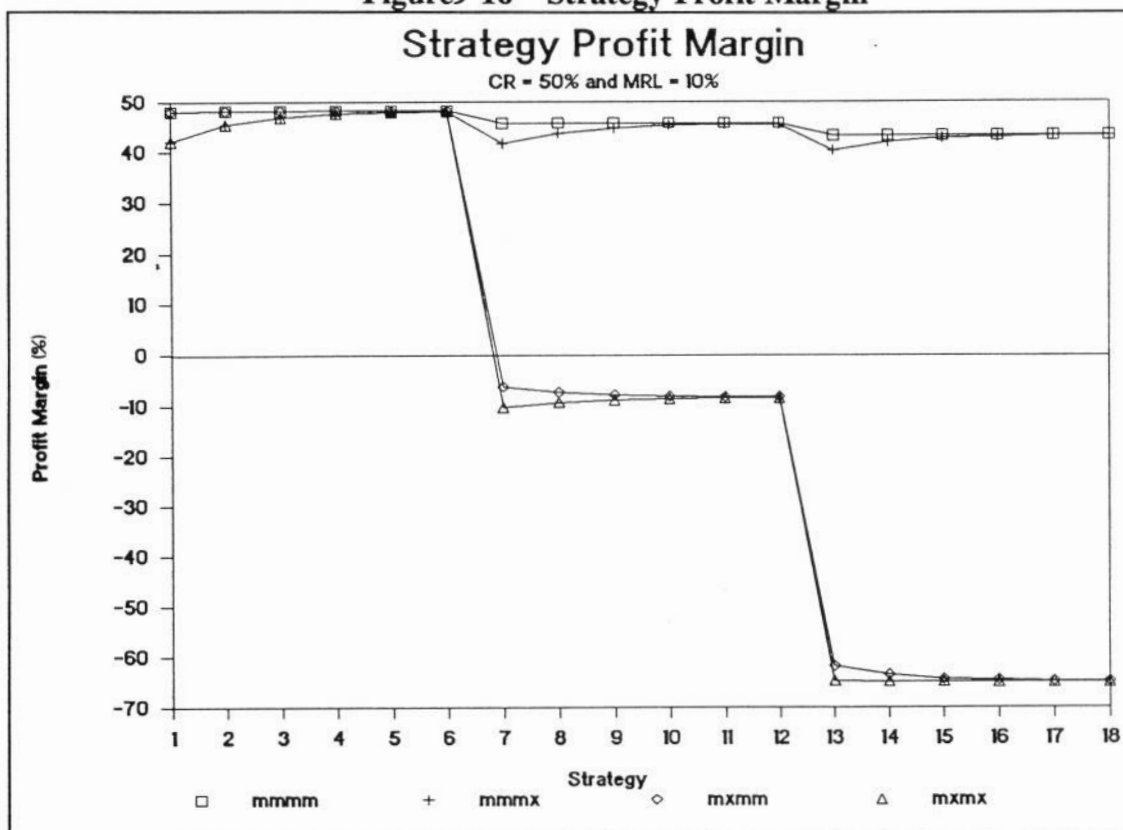


Figure9-17 Strategy Profit Margin

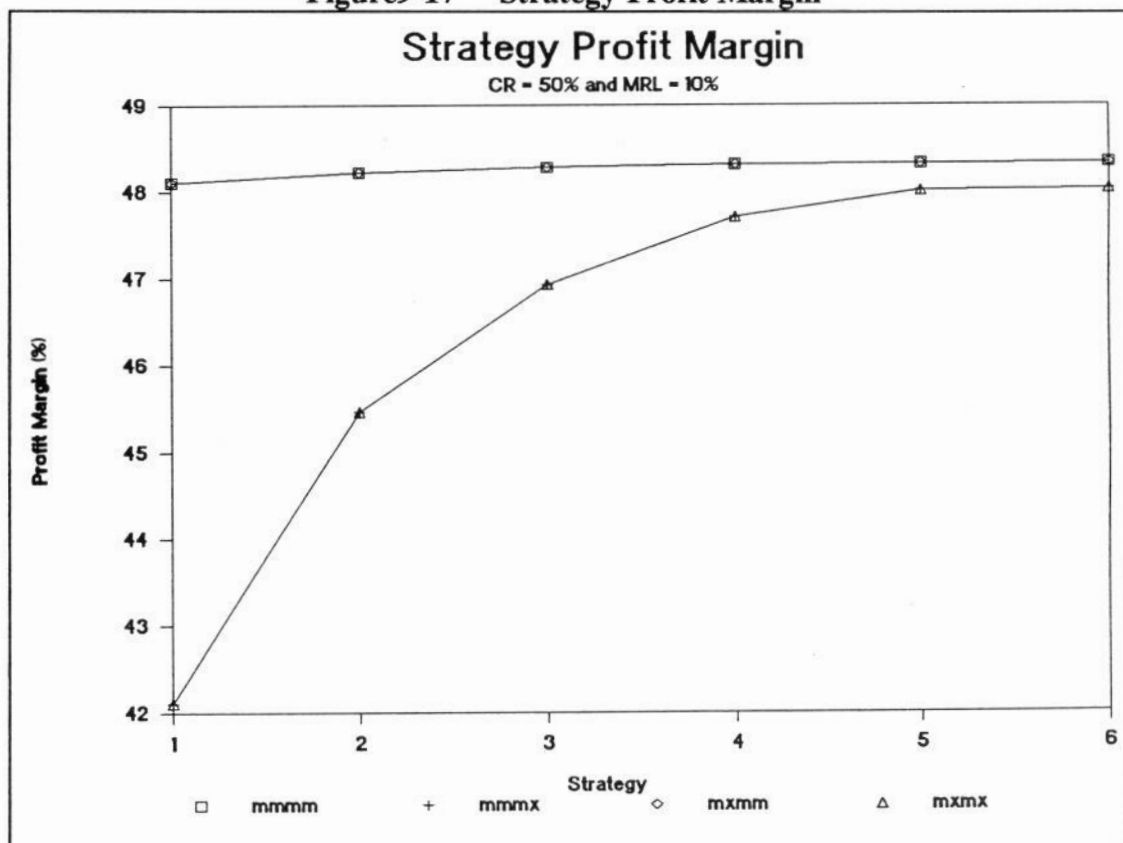


Figure9-18 Strategy Profit Margin

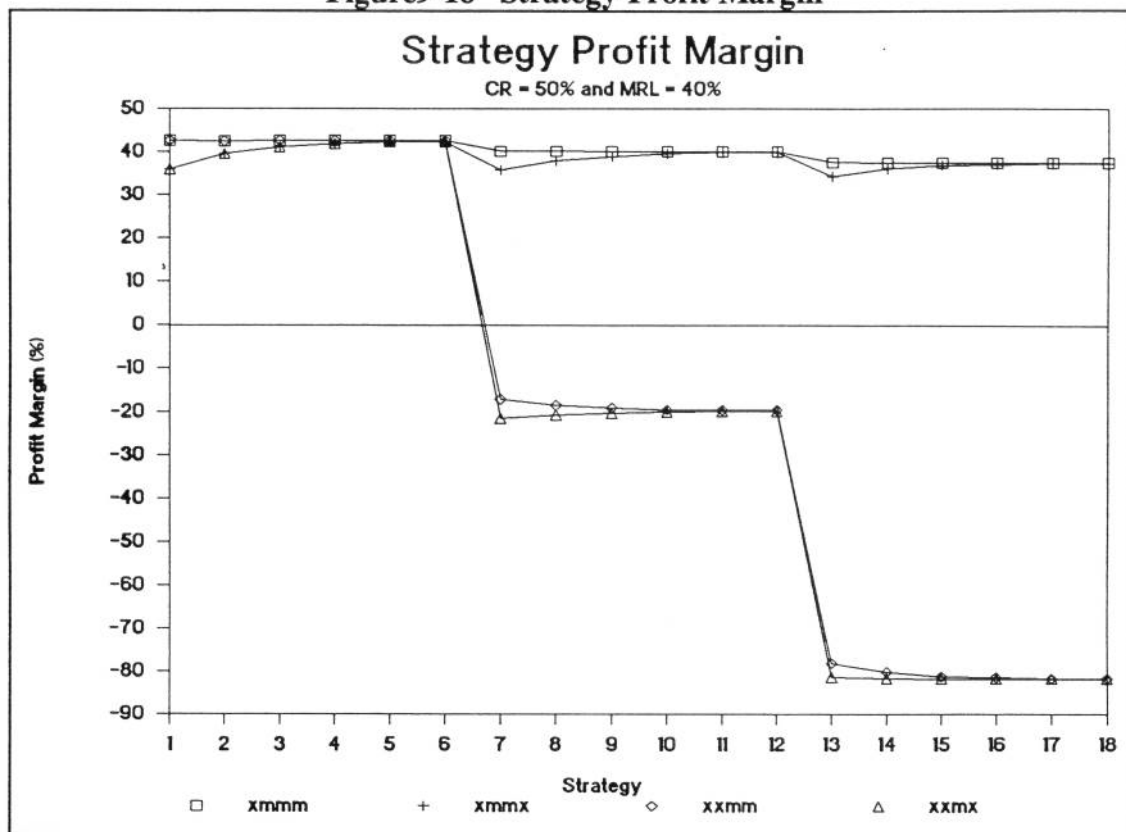
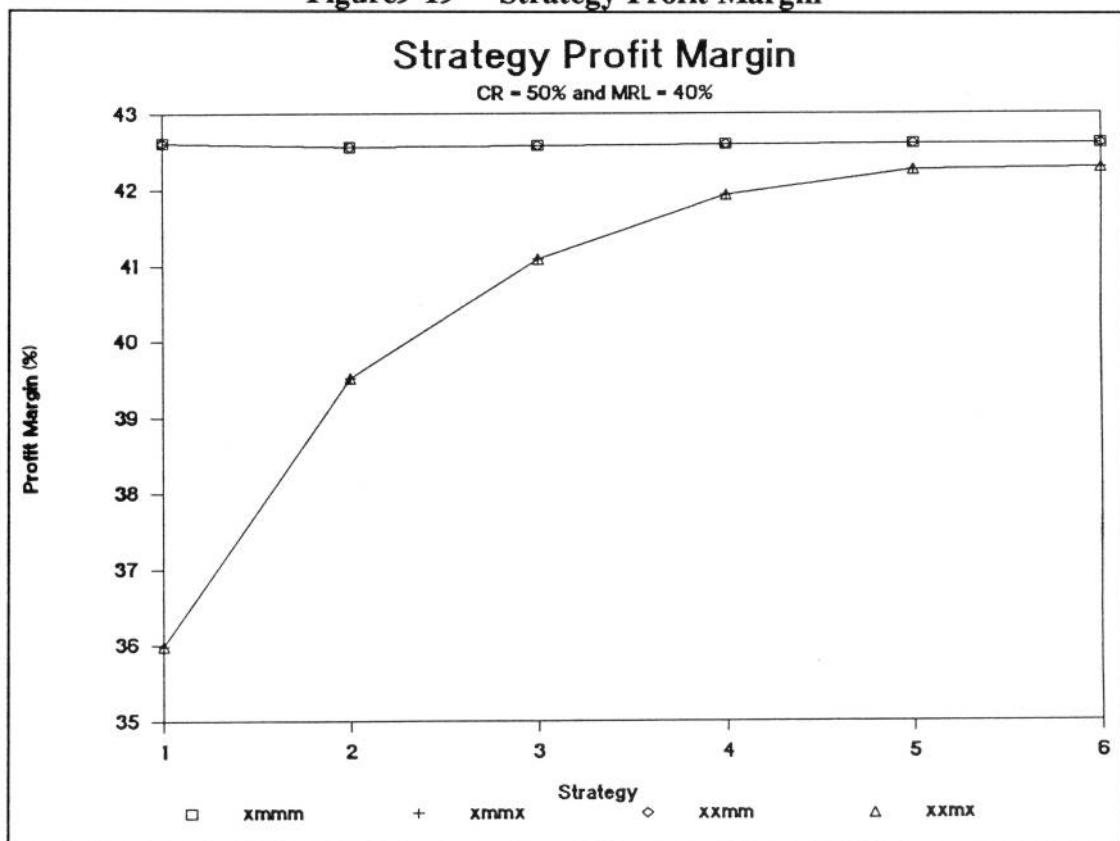


Figure9-19 Strategy Profit Margin



CHAPTER (10)

CONCLUSIONS

This chapter provides the summary and conclusions of this thesis. Section 10.1 summarizes the objectives and the achievements. Section 10.2 suggests guidelines for the practical implementation of the systematic approach for punctuality management in the airline business. Section 10.3 gives the limitations of this research and section 10.4 suggest the areas of further research.

10.1 OBJECTIVES AND ACHIEVEMENTS:

The objective of this research is to formulate a systematic approach to support airline management in decision making for schedule punctuality considering all PM issues and possible management strategies. In this research emphasis is placed on evaluation strategies concerning *schedule planning* and internal airline factors influencing punctuality. The following are the major sub objectives (in *italic and bold*):

Formulation of the structure of punctuality management system. This formulation includes the description of the entire system's model and components. Figure (2-5) shows the punctuality management system structure. It shows the relationships between the system's input and output. The percentage of passengers revenue loss, extra operating cost and punctuality performance level are output variables for this system. Slack times, schedule plan including aircraft plan and its utilization, airline resources such as manpower crews and reliability standards are the major input variables. There are five models in the PM system; disturbance model, recovery model, passengers attitude model, revenue model and cost model.

The first model is the **Disturbance Model**. This model analyses the delay data statistically to develop the probability distribution function for delay frequency functions and delay time functions. These delay functions are used in the schedule simulation model (SKDMOD) where a random number generator is used to assign delays to different flights in an aircraft cycle. Second is the **Recovery Model**. This model is the most difficult model in the Punctuality Management system where the propagated delays in the schedule are determined. Reactionary delays are estimated by the simulation of different management strategies concerning slack in ground time, spare aircraft and maximum delay time to assign spare aircraft if delay occurs. Third is the **Passenger Attitude Model**. The purpose of this model is to determine the impact of delays (disturbances) on passengers and their attitudes towards the

airline in future. The delay impact function and passenger revenue loss functions are developed from the analysis of the survey. The fourth model is the **Revenue Model**. This model demonstrates the effect of punctuality management strategies on airline revenue using the percentage revenue loss function. The revenue function is formulated in Chapter 8. Fifth is the **Cost Model**. This model demonstrates the effect of schedule punctuality management strategies on the total operating cost using the mathematical cost function which is formulated in Chapter 8.

Classification of aircraft schedule disturbances including delays and cancellations. Determine general delay frequency and delay time distribution functions from a statistical analysis of the historical delay data. The original delay distribution functions and the reactionary delay function which comes as a result of propagation of the original delay in the schedule were estimated from a large sample. Figure 3-4 shows the general delay frequency distribution function which include analysis of 85045 flights during one year of scheduled operations. and figure 3-5 shows the delay time distribution function. 15% of the total flights are disturbed flights where 9% are delays and 6% are cancellations. Delays are classified into four types of delay. Original delays represent 61% of the general delays, reactionary delays represent 26% , connection delays represent 3% and others 10%. This type of classification is new and it represents a major contribution of this part of the research. Distribution function is displayed for each type of delay graphically. Figures 3-15, 3-17 and 3-19 illustrate the frequency distribution functions for all delays types.

In depth analysis of each type of delay including general, original, and reactionary by different category of delay i.e. marketing delays, technical delays, operational delays is carried out in Chapter 3.

Estimation of these delay functions including general, original and reactionary into synthetic distribution functions such as lognormal and Weibull. Delay Distributions are estimated by fitting lognormal distribution function and Weibull distribution functions. Lognormal parameters are estimated analytically as in section 4-3. Weibull parameters are determined using a nomograph (figure 4-5). The estimation using a nomograph is less accurate due to manual reading and it gives in this case only the initial estimates for iterative computational and fitting procedure.

The lognormal distribution estimation which has been represented by general, original and reactionary delays is the most acceptable distribution as compared to Weibull, in spite of the fact that lognormal estimation has a high percentage error for the first half of an hour delay time. The use of empirical distribution is also a valid option in this case if a higher level of accuracy is needed. For the purpose of schedule simulation in SKDMOD the lognormal distribution is used.

Measurement of passengers attitude towards schedule punctuality by conducting passengers interview survey. Following a pilot, a survey of 262 passengers was carried out in order to estimate passengers' impact functions and revenue loss functions for all passengers, business passengers and vacationers. The average impact functions comparison chart appears in figure (5-5) which is broken down by passenger's trip purpose. Three curves, the middle curve represents the general delay impact, the top curve represents the business impact function and the lower curve represents the vacationers impact function. It suggests business travellers are more highly impacted by schedule delays and cancellations.

A comparison of the *passenger revenue loss* functions shown in figure (5-10) relate revenue loss to passenger's trip purpose. Similar findings, to the delay impact, are found here where the middle curve represents the general revenue loss, the top curve represents the business revenue loss function and the lower curve represents the vacationers revenue loss function. Business passengers who are lost are always higher than general and vacation passengers. The estimation of this function poses formidable conceptual and practical issues. It remains the weakest model in the set of 5 models.

Development of schedule simulation prototype model in which the planned aircraft schedule is simulated using different management strategies. A PC based interactive simulation model is developed using PC Simscript II.5. The simulation concentrates on the evaluation of management decisions involving the provision of slack times in a flight's block time and aircraft ground times and spare aircraft. These are examples of the schedule planning strategies. Maximum delay time to assign a spare aircraft (MDAS) is a third type of management strategy that is used in the simulation model. MDAS is one of the operational strategies. The schedule simulation model contains two major processes one for aircraft assignment in which the system assigns aircraft to flight and the second major process is the scheduling process where a delay function is inserted.

"SKDMOD" is a prototype aircraft schedule simulation model. It is used with delay functions determined earlier. Three different schedule plans are used for simulation illustrating three ground times (30, 40 and 50 minutes as a schedule ground time where the scheduled ground time equals minimum ground time plus the slack ground time). For each schedule plan, six MDAS (Maximum Delay to Assign Spare aircraft) strategies are simulated to determine the impact of the MDAS on the entire punctuality. Two spare aircraft are available for spare operations whenever it is needed. The schedule simulated is based on part of the domestic network in Saudia Arabia. For the analysis purposes the utilization of these spare aircraft is accumulated in terms of block hours throughout the entire simulation period (200 days) for each strategy (18 strategies). Delays are classified as delay or a serious delay.

Optimization analysis of each management strategy in terms of the trade off between passengers convenience and extra operating cost incurred. The formulation of an optimization formula enables the determination of the best strategy to follow based on two decision criteria. One criterion is profit and the second is profit margin. Also, sensitivity analysis of major airline parameters is performed to demonstrate more global vision of punctuality management. To enable this, a program is developed called "OPTIM" to evaluate the profit and profit margin and show the results of the sensitivity analysis around the ranges of the airline internal parameters (AIP) including CR (cost to revenue ratio), BA (hourly cost of spare operation to normal operations), J (the extra percentage cost to the normal hourly cost due to extra active aircraft in the schedule) and MRL (maximum percentage for passenger revenue loss) which are discussed in detail in Chapter 9. The output of OPTIM program are the strategies' detailed results including Ground Times, MDAS, calculated percentage of revenue loss, cost, revenue, profit and profit margin

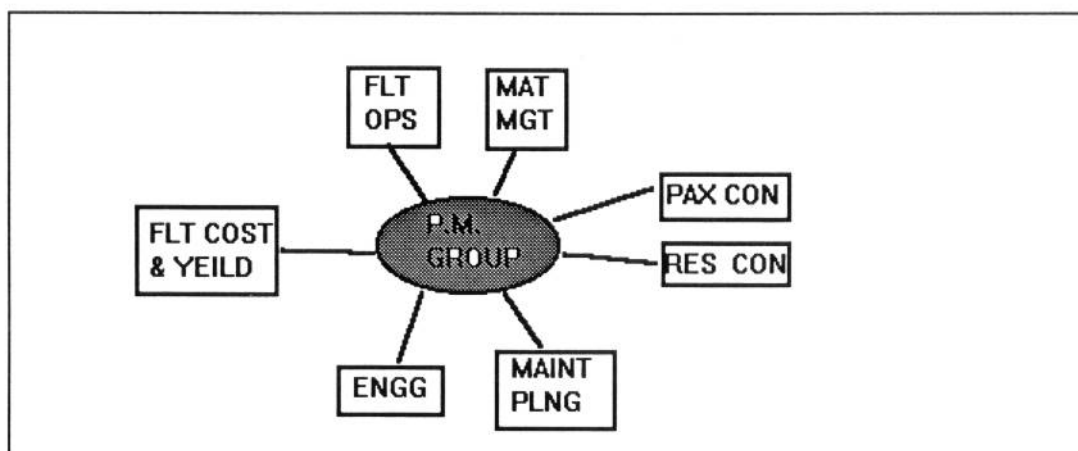
Figures 9-16, 9-17, 9-18 and 9-19 summarize the profit margin for all strategies using different values of the airline parameters. These are subject to detailed discussion in Chapter 9.

10.2 Practical Implementation :

Punctuality Management is a complex real airline problem. This thesis describes here a systematic approach for management all the issues of punctuality management. This approach is essential in maintaining a consistent operational mode especially for a medium to large carrier.

Before discussing the PM approach two important points have to be considered. First, airline corporate objectives that are related to punctuality have to come to terms with the trade-off between high services standards and better passenger satisfaction and the additional operational cost. Second, it is necessary to ensure the right corporate organization structure. PM requires an efficient and effective means of communications among all the parties concerned in the organization i.e. Flight Operations, Technical Operations, Materials, Marketing, Finance and Corporate Planning.

It is recommended that a punctuality management group is established to perform these functions. The major function of this group is to formulate management strategies and evaluate them using PM approach with coordination with the groups involved in Reservation Control, Passenger Control, Operational Planning from Flight Operations, Materials Management, Maintenance Planning and Engineering from Technical and Flight Costing and Revenue from Finance. Other functions of PM group are to develop the operational/planning PM strategies which are applicable to the airline based on its resources. A PM group will have a more effective role if it has the necessary authority and support from top management in the airline.



Punctuality Management Approach:

After preparing the right environment for effective punctuality management with respect to airline corporate objectives and airline corporate organization structure, guidelines of the PM approach are :

- 1) Understand the airline corporate operational strategy(ies) if it exists or formulate new strategy(ies).
- 2) Examine the organizational structure for all the related airline divisions with regard to effective communications and PM related issues.
- 3) Be aware of all corporate and divisional constraints.
- 4) Develop PM strategies for each schedule period. Provide estimates for slack times for scheduled ground times (minimum/maximum ground times), estimates maximum delay time to assign spare aircraft (MDAS) values and others.
- 5) Measure the schedule disturbances and estimate the probability distribution function and its mean and standard deviation parameters.
- 6) Simulate the draft schedule using SKDMOD model to determine the original and reactionary delays for both general delays and serious delays.
- 7) Estimate the passenger impact function and the passenger revenue loss function.
- 8) Simulate different PM strategies using SKDMOD and analyze simulation results. Evaluate the schedule delays, delay times and average daily delay time.
- 9) Compare schedule simulation results with the target performance values in delays, delay times and average daily delay time. If schedule performance is acceptable then go to step 10, and if not repeat steps 4 to 8.
- 10) Determine actual airline values for Airline Internal Parameters (AIP) such as RC, BA, J and MRL values.
- 11) Determine the optimum strategy(ies) for schedule implementation based on profit and profit margin criteria using OPTIM.

- 12) Monitor the schedule performance; Punctuality Performance Level, operating cost and revenue to make decisions accordingly.

This approach has most of the elements and tools of a Decision Support System (DSS) framework though it requires more detailed work for practical implementation if it is to be used as a structured procedure.

10.3 Limitations of the research:

The main objective of the research was to develop and integrate all the components of punctuality management in one system for the first time. All of the models in the system are simplified to some extent. All are unsatisfactory in same practical respect.

In particular the revenue loss is determined by measuring the passenger attitude in two steps. First, the impact function which is determined from the passenger survey. Second, the revenue loss function is estimated from the impact function and the absolute value of the maximum revenue loss percentage which is found from the survey. This is an estimation which needs more conceptual and empirical work.

The aircraft schedule simulation model (SKDMOD) is a prototype model which demonstrates the management strategies in schedule operations. It has some assumptions to make it manageable. The SKDMOD scope needs to include more aircraft types, cover operational constraints in more details especially in aircraft assignment and diversion.

10.4 Further Research:

The following is the areas that needs more work to make the schedule punctuality management more operational. Of course it is related to the limitations mentioned above:

Improving the revenue loss function is important especially for strategies optimization. One side is to differentiate between the passenger revenue losses and the passenger trip losses. Because passengers attitudes changes in time according to many factors. Second is to determine whether departure or arrival delay affects passengers more.

Expanding the scope of the aircraft schedule simulation model (SKDMOD) is needed to cover more operational constraints in the aircraft assignment process and more aircraft types in the schedule. One way could be to develop an expert system for aircraft assignment and aircraft diversion and integrate it with SKDMOD.

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APPENDIX (A)

DELAY CLASSIFICATION

This appendix introduces the background of delays policies, definition of delays, responsibilities, disputes. Section A.2 illustrates computation of delays for originating station, turnaround station, through station, resumed scheduled flights and return flights. Section A.3 illustrates the time classification of delays that requires reporting. Section A.4 explain the methodology of constructing the delay data including delay messages, irregularity reports and descrepency reports with examples for the illustration purposes.

For different delays airlines assign delay codes to designate the reason for delays. Section A.5 explains the allocation of delays codes in the airline operation. Section A.6 shows the list of delay codes used in the airline including marketing delays, technical delays, flight operations delays, spare and materials delays, system delays, airport and government delays including passport and customs, this list reflect SAUDIA codes. The delay codes changes from one airline to other according to airline requirements and environment.

Section A.7 explain the reliability of the delay data and codes used in this research for the purpose of delay analysis. Section A.8 concludes appendix (A).

A.1 INTRODUCTION:

This appendix is essential to give the background of the data used for the delay analysis and distribution estimation. In this appendix an overview of delays classification will be discussed. Computation methodology for different delays, construction of delay data, allocation of delay codes and data reliability will also be presented.

Sources of information obtained in this appendix are different according to the need; researcher experiences, Saudia Marketing and Ground Manual and discussions held with responsible managers in the airport.

A.1.1 Saudia Policy:

"Saudia's standard of service requires that a policy of on-time and safe operations be maintained. However, safety and accuracy shall never be sacrificed in the interest of reducing delays or dispatching flights on time".

"Proper delay reporting and classification is always required in order to furnish Saudia Management with the correct information, so that appropriate corrective action may be taken to overcome performance deficiencies and so improve Customer service". (Saudia Marketing and Ground Services Manual (71)).

A.1.2 Definitions:**Delays:**

Delay is incurred when a flight departs later than the published scheduled departure time, the amount of such a delay will be the difference between the schedule time of departure and the arrival time of departure.

Minimum turnaround time:

Standard time for inbound flight to turnaround for another outbound flight. Each aircraft type has its own standard minimum turnaround time. Domestic turnaround time is different from International turnaround time for the same aircraft.

Delivery time:

Time of delivering aircraft to terminal from maintenance; Marketing has standard delivery time for each aircraft which varies sometime from station to station.

A.1.3 Responsibility:

The Station Manager or the Flight Information Coordinator or his delegated representative determines the appropriate classifications for each flight delay, by investigating and coordinating with the departments involved.

System Airport Services monitor agency of delay classifications and has the authority to advise the station concerned of the correct delay code to

be used based on the facts contained in the delay discrepancy report (to be submitted on a form COM-125).

It is the responsibility of the reporting station to record the reason for a delay. System Airport Services retains the responsibility to ensure that each delay or cancellation or other irregularity is properly classified and recorded.

A.1.4 Disputes:

When a difference of opinion arises over the classification of a delay, the Station Manager responsible has the authority to give a ruling after having investigated the case. If after such inquiries there appears to be a discrepancy the CODE 03 of delay codes as appears in Section 1.6 is applied and the matter is referred to the Manager-System Airport Services for arbitration and final classification. System Airport Services must in these cases have all relevant facts and details. This step is taken after the station staff concerned have taken exhaustive steps to rationalize the delay code locally.

Section 1.4.3. of this chapter shows a sample discrepancy report.

A.2 COMPUTATION OF DELAYS:

A.2.1 Computation of Delays for Originating Stations:

When computing a delay at the station of origin or point of turn-around it is required to determine if the equipment was available with the station at the required time to make an on-time departure.

Example (1):

If the L1011 aircraft delivery time to station from Maintenance is two hours before departure; and

	<u>Time</u>
Aircraft available to terminal	0700
Schedule time of departure	0900
Actual time of departure	0912
Delay Amount	0012

Although L-1011 aircraft was available to terminal on time two hours

before departure, but twelve (12) minutes of delay as indicated by late ATD.

Example (2):

If B-707 delivery time to station from Maintenance is one hour and 15 minutes before departure; and

	<u>Time</u>
Aircraft available to terminal	0800
Scheduled time of departure	0900
Actual time of departure	0915
Delay amount	0015

Since the delivery time is one hour and fifteen minutes, STD is 0900 hours and the aircraft has to be 0745 hours, so 0015 minutes due to late arrival from maintenance causes the ATD to be 0915.

Example (3):

If B737 delivery time to station from Maintenance is one before departure; and

	<u>Time</u>
Aircraft available to terminal	0800
Schedule time of departure	0830
Actual time of departure	0915
Delay amount	0045

Since STD is 0830 hours and B737 delivery time is one hour then aircraft has to be at the terminal at 0730 hours. So the aircraft has delayed for 0030 minutes due to late aircraft release from maintenance "delay code 42". In addition to the 0030 minutes delay the aircraft is supposed to depart at 0900 hours but ATD was 0915 which means that a second delay of 15 minutes occurred due to a reason as appropriate. Then total delay will be 45 minutes.

A.2.2 Computation of Delays for Turn-around Stations:

The same approach as mentioned in 1.2.1. is applied to flight turnarounds, but using the minimum turnaround times.

Example:

If L-1011 standard minimum turn-around time is two hours; and

	<u>Time</u>
Inbound flight arrivals	1000
Schedule time of departure	1100
Actual time of departure	1230
Delay amount	0130

Total delay time is one hour and 30 minutes due to two reasons; first is late arrival due to a previous delay which existed in the origin station of this flight by one hour because it was supposed to arrive at 0900 hours (standard minimum turnaround time is two hours). The second delay is 0030 minutes for appropriate reason due to ATD of 1230 not 1200.

A.2.3 Computation of Delays for Through Stations:

A delay is incurred for a through station when a flight remains at a transit station longer than the published ground time, and the amount of delay is the difference between the scheduled ground time and the actual ground time regardless of how late the flight may be operating.

Example:

	<u>Scheduled Time</u>	<u>Actual Time</u>
Arr time	0830	0930
Dep Time	0930	1045
Ground Time	0100	0115

Amount of through station delay is 0015 minutes; the difference between scheduled ground time and actual ground time. Total delay time is 0115; 0100 is due to late arrival and 0015 minutes is a delay in the through station as appropriate.

Exceptions:

When a flight arrives ahead of schedule time, the amount of delay is the difference between the actual and scheduled departure times even though the scheduled ground time was exceeded.

Example:

	<u>Scheduled Time</u>	<u>Actual Time</u>
Arr time	0830	0800
Dep Time	0930	1045
Ground Time	0100	0245

Amount of delay in through station is 0115 hours although the actual ground delay is 0145 hours.

A.2.4 Resumed Schedule Flights:**Definitions:**

A delay is occurred when a flight departs later than the scheduled departure time shown in the published timetable for the point of resumption regardless of the resumed departure time.

Flights resumed at a station other than the published stop show a delay whenever they depart later than the origination time established on the Operational Plan or Supplemental Operational Plan.

A.2.5 Return Flights:

Return flight is defined when a flight returns from the runway or from flight to the airport of last departure. The delay is charged only for the actual amount of airport delay time when it returns:

Example (1):

Scheduled Dep Time	0830	Actual Dep Time	0830
Flight returns and blocks			0850
Second Dep Time			0930

Amount of delay from 0850 TO 0930 = 0040 Minutes.

Example (2):

Flight departs later after having incurred a delay, returns and then departs a second time;

Scheduled Dep Time 0830 Actual Dep Time 0900

Flight has 0030 Minutes delay.

Flight returns and blocks	1015
Second Dep Time	1100

Flight has 0045 Minutes delay.

Such a flight has incurred two delays and each has to be classified separately. Total delay time is 0115 although difference between first STD and second departure time is 0230 hours.

A.2.6 Delay On Runways:

Irregularities which occur subsequent to a flight's departure from the ramp and before take-off causing the engines to be shut down for the purpose of deplaning passengers or repairing the aircraft are considered as runway delays. For the purpose of delay classification aircraft is considered to have returned from the runway and the second "in time" is the time when the engines were shut down. The delay is the difference between second departure time and INTIME.

Irregularities which occur subsequent to a flight landing at a station but prior to its arrival at the normal ground handling point, causing the engines to be shut down for the reasons given in previous paragraph, the "IN TIME" will be considered the time at which the engines were stopped.

A.2.7 Delays Due to Late Arrival of Turnaround Aircraft:

Delays of aircraft because of late arrival of inbound flights which are supposed to turnaround for outbound flight is the difference between the STD and the latest departure time

Example:

	<u>Scheduled</u>	<u>Actual</u>
Arrival time of inbound flight	1845	1945
Dep time of turnaround flight	1930	
Turnaround time min.	45	45
Latest dep time of flight	2030	2030

Therefore maximum delay chargeable to late inbound flight is the difference between the STD and latest dep time of aircraft i.e. 0100 Hrs.

A.3 TIME CLASSIFICATION OF DELAYS THAT REQUIRE REPORTING:

Only delays of more than five minutes are reported and included on line while delays less than five minutes are ignored.

Assuming that this little delay could be overcome, larger delays which are more than 12 hours, are not existed because such flights are cancelled and re-originated with appropriate resumed flight prefix. Flight prefixes are different from schedule flights and non-schedule flights.

A.4 CONSTRUCTION OF DELAY DATA:**A.4.1 Delay Messages:**

This message shall be sent on all flights that are delayed departing from their originating stations, or from transiting stations enroute. It shall be addressed in all cases to all the concerned departments:

System Airport Services
Operational Planning
Flight Despatch
Crew Scheduling

The message also addressed to GM-System Airport & Passenger Services, the appropriate regional General Manager and Station Manager and F.I.C. Office at the destination station.

Also any enroute stations and local addresses as may require the

information.

The message shall be along the lines of the following format:

- 1) Station, Flight No., Date.
- 2) Aircraft Registration.
- 3) Length of delay/delay code.

N.B. If delay involves more than one code, the breakdown by individual times and codes must be shown.

- 4) Brief description of delay.
- 5) Total passengers on board, by First and Economy. Also the number of passengers lost, if any, due to the delay and the reason.
- 6) Action taken to prevent recurrence of problem, if possible, plus any other relevant information that may be considered important.
- 7) Inconvenience to passenger (passenger reaction/attitude).
- 8) Expenses involved (cost of snacks, meals, and transportation, etc.)

A.4.2 Irregularity Reports:

All delays and other irregularities which occur in a day from 00:01 to 24:00 are summarized in the irregularity report by Operations Planning department in Flight Operations. Each irregularity report has three sections; first section is irregularity report for scheduled flights, second is for additional flights and the third is for cargo flights. All those irregularities which occur from scheduled flights are summarized by delays and other irregularities. The delay summary is shown by aircraft type which contains information about flight number, tail number, station where the delay happened, delay time, delay code and more explanation about the delay.

In the other irregularities, information about cancellations / diversions, equipment substitutions and late terminations are also shown in the daily irregularities report.

Attached to this section is a sample of the daily irregularity report issued

by Operations Planning Department for the 30th and 31st December 1986. The following are illustrated examples extracted from the daily report.

Example (1):

In the 30th December report, B747 of flight SV338 tail number IM at JED station had 8 minutes delay with delay code 85 which is 'Airport Restrictions'. The delay was actually due to taxiway lights and consequently it was necessary to hold aircraft till finished.

Example (2):

Another B747 flight number SV344 with tail number IS at RUH station had a delay of 55 minutes due to aircraft held on ground in RUH waiting for weather improvement in Delhi. The delay code is 72 which is weather delay at destination station.

Example (3):

On 30th December 1986, A-300 aircraft scheduled for flight SV325 with tail number JD had a delay of one hour and 24 minutes due to late arrival from the prior flight SV320 originated from RUH. RUH delay was a technical delay, that's why the delay is coded 40. The flight had a second delay for 21 minutes due to late arrival of SV320 because of time lost enroute. So the total delay time for SV325 is 01 hour and 45 minutes.

A.4.3 Discrepancy Report:

Attached to this section is a sample of discrepancy report COM-125 which is issued in case of dispute of coding the delays as mentioned previously in Section 1.1.4.

The discrepancy report shows that Flight Number SV887 had a delay in ABHA (domestic station) on 08 July 1987 for a length of 2 hours and 20 minutes. The scheduled departure time was 14:45 while the actual time of departure was 17:05.

Duty Supervisor of ABHA station had a dispute of delay coding for this delay; either to assign code 66 Late Flight Deck Crew Boarding or Departure Procedure or code 67 Cabin Crew Shortage.

As shown in the translation of the report, the delay coding is reported as a discrepancy because of the unclear statement for the reasons of late crew boarding.

Delay code 66 is Late Flight Deck Crew Boarding or departure control other than connections and stand by.

Delay code 67 is 'Cabin Crew Shortage' due to sickness, awaiting stand by, flight time limitations, crew meals, valid visa and/or health documents.

Manager - System Airport Services will investigate more than the concerned areas and after discussing it with Station Manager ABHA and Flight Operations, Manager - System Airport Services will decide the delay code for this flight.

The percentage of discrepancies is represented by percentage of pending delays which represent minimal percentage of total delay (5%) and of total delay time (4%).

A.5 ALLOCATION OF DELAY CODES:

- (a) Flight Information Control (FIC) classifies the flight delay code from one of the list of delay codes mentioned in section 1.6. Responsibility of delay and explanations are stated in a delay message reported to System Airport Services, FIC and others concerned.
- (b) In case of dispute of opinion in coding among the FIC and the staff concerned, the station manager has to be involved in order to finalize the matter. Rarely a station manager has to assign a delay code number 3 when the whole matter is transferred to Manager - System Services to investigate and finalize the subject. A Discrepancy Report (COM-125 Form) is submitted from the Station Manager to System Airport Services. Section 1.4.3 has a live/actual sample of this report.
- (c) After approving COM-125, Operations Planning updates the online Flight Operations Information System (FOIS) which holds the flight details. By end of the day, Operations Planning produces a summary investigation report of the events that happened during that day. Section 1.4.2 shows an actual example of a daily irregularity report.

A.6 DELAY CODES USED IN AIRCRAFT MOVEMENT:

The following delay codes are classified in nine sections according to the departmental responsibilities and for airline use. The coding as appeared in this section are quoted from Saudia Marketing and Ground Manual as used in actual delay allocation and for On-time Performance Analysis.

SECTION 1 - Airline Internal Use:

- 03 Pending - Temporary classification (to be used when the cause is not known or under investigation) to be used for a maximum period of seven (7) days after which if no agreement is reached the code will change to "PERSONNEL" and charged to the concerned department.
- 04 Time Gained - To be used at enroute stations only when flight arrives later then scheduled arrival and departs before expiring of allotted ground time.
- 05 Time Lost Enroute
- 09 Equipment Shortage - Resulting from movements such as: Teachers, Haj, Extra Sections, etc.

Reactionary Delays:

- 20 Turn-around - Late arrival ex Marketing delay.
- 30 Turn-around - Late arrival ex Materials Management Delay.
- 40 Turn-around -Late arrival ex Maintenance Delay.
- 50 Turn-around - Late arrival ex Automation System Delay.
- 60 Turn-around - Late arrival ex Flight Operations Delay.
- 70 Turn-around -Late arrival ex Weather Delay.
- 80 Turn-around -Late arrival ex Airport Authority Delay
- 90 Turn-around - Late arrival ex Airport Closure Delay

SECTION 2 - Marketing:

- 10 Damage - Damage caused to aircraft by Marketing or vendors personnel.

Passenger & Baggage:

- 11 Late Check-in - Acceptance after deadline.
- 12 Late Check-in - Congestion at check-in area.
- 13 Check-in Error - Passenger and baggage.
- 14 Oversales Booking Errors
- 15 Boarding - Discrepancies and paging
- 16 Commercial Publicity/Passenger Convenience, Illness/death - Connections.
- 17 Catering Order - Late or incorrect order given to suppliers.
- 18 Baggage Handling

Cargo:

- 20 Documentation - Errors, etc.
- 22 Late Positioning of Cargo
- 23 Sales Decision - Discretionary for late acceptance of cargo/mail.
- 24 Inadequate Packing
- 25 Oversales Booking Errors
- 26 Incorrect Build-up of ULD

Aircraft & Ramp Handling:

- 31 Aircraft Documentation - Weight and Balance, General Declaration. Passenger Manifest, Payload/Fuel Release.
- 32 Loading/Unloading ULD - Bulky special load, cabin load, lack of loading staff.

- 33 Loading Equipment - Lack of Hiloader, steps, conveyor belts, tractors.
- 34 Servicing Equipment - Lack of or breakdown, lack of staff to operate.
- 35 Aircraft Cleaning
- 37 Catering - Late delivery to loading.
- 63 Late Cabin Crew Boarding - On departure procedures, other than connection and standby.
- 67 Cabin Crew Shortage - Sickness, awaiting standby, flight time limitations, crew meals, valid visa, health documents.
- 68 Cabin Crew Special Request - Not within operational requirements.
- 82 Security - Involving passengers/cargo including bomb scares.
- 83 Immigration, Customs and Health

SECTION 3 - Technical & Aircraft Movement:

- 39 Maintenance Equipment/Servicing Equipment - (Including aircraft test equipment) lack of or breakdown, lack of staff to operate.
- 41 Aircraft Defects:

Delay Due to Technical Problem - Malfunction of aircraft, engines or component parts thereof.

Origin Station

When a malfunction occurred or discovered after aircraft delivery to terminal, the delay is charged to origin station. If the malfunction could have been repaired without delay or detriment to station functions but parts were unavailable or delayed, entire delay should be charged to parts.

Enroute Station:

When malfunction requires longer than scheduled ground time to

correct. Where malfunction is repaired within allotted ground time but interferes with normal station functions, all delays should be charged to mechanical, provided station functions are handled in a reasonable time.

At Turn-around Stations:

If scheduled turn-around time does not exceed the minimum turn-around time of one hour, whichever is greater, these stations should be considered as "Enroute Stations" for Mechanical Delay classification purposes.

42 Scheduled Maintenance, Late Received for Service -

Aircraft not available at delivery time to terminal due to scheduled/unscheduled maintenance, not completed within time standard, or when there are more flights to handle simultaneously than normally scheduled at a given time.

43 Non-Scheduled Maintenance - Non-scheduled maintenance, special checks and/or additional works beyond normal maintenance schedule.

46 Aircraft Change - Aircraft change for technical reasons, indirectly by a mechanical problem, e.g. equipment taken from flight due to mechanical problem on the equipment assigned to that higher priority flight. Also includes equipment shortage due to a continuing mechanical problem on an aircraft that prohibits flight assignment.

47 Standby Aircraft - Lack of standby aircraft for technical reasons.

48 Personnel - Flight delay, cancellation or irregularity resulting from error or negligence by Technical Personnel.

49 Maintenance Routing - Delay due to routing of aircraft for maintenance considerations. Also includes delays due to transport of Technical personnel and/or tooling and equipment for AOG Aircraft at another station.

84 Airport Facilities - Parking stands, ramp congestion, lighting, buildings, gate limitations, mobile lounge.

SECTION 4 - Material Management:

36 Fueling/defueling - Fueling/defueling caused by fueler.

- 44 Spare Parts, Lack of, Personnel Errors/Damage - Delay or aircraft shortage resulting from non-availability of inventory part which is allotted to this station. This includes the non-availability of a pool item that should be provided by another airline.

Delay or aircraft shortage resulting from requirement for part not provisioned at this station.

Delay resulting from Materials Management personnel. This includes deliveries from stores taking more than 20 minutes. Damage to parts as a result of mishandling by Materials Management staff.

- 45 AOG Spares, to be carried to another Station - Delay caused by necessity to transport AOG part to another station.

SECTION 5 - System Delays:

- 51 Damage to Aircraft - Damage during Flight Operations, bird or lightning strike, turbulence, heavy or overweight landing, collision during taxing.

EDP/Automated Equipment Failure:

- 55 Automated Equipment Failure - Departure Control.
- 56 Automated Equipment Failure - Cargo Preparation/Documentation.
- 57 Automated Equipment Failure - Flight Plan.
- 58 Automated/Equipment Failure - Other Systems.

SECTION 6 - Flight Operations:

- 61 Flight Plan - Completion or change of Flight Documentation/General Declaration
- 62 Operational Requirement - Extra fuel/top off fuel.
- 64 Late Flight Deck Crew Boarding or Departure Procedures - Flight Deck crew shortage, sickness awaiting standby. Flight

Time limitations crew meals, valid visa, health documents, late arrival of flight deck crew, etc.

- 65 Flight Deck Crew Special Request - Not within operational requirements, personal errors/damage.
- 66 Late Flight Deck Crew Boarding or Departure Procedures - Other than connection and standby.
- 69 Personnel - Flight delay, cancellation or irregularity resulting from error or negligence by Operations personnel.
- 81 Air Traffic Services Clearance, including ATC -
- 96 Movement Control - Re-routing, diversion, consolidation, cancellation of flights for reason other than technical/operational decision.

SECTION 8 - Airport & Government Authorities:

- 27 Incorrect Mail Documentation - Packing etc.
- 28 Late Positioning of Mail
- 29 Late Acceptance of Mail
- 85 Restrictions - Airport and/or runway closed due to obstructions, industrial or political unrest, noise abatement, curfew, etc.
- 86 Airport Closed, Security including Special Flights, Airport closed for VIP Movements, Aircraft used for VIP Movement.
- 87 No Gate/Stand Available due to own airline activity.
- 88 Operational Limitation at Destination - Excluding weather and ATC.

SECTION 9 - Miscellaneous:

- 97 Industrial Action Within Own Airline
- 98 Industrial Action Outside Own Airline
- 99 Not Elsewhere Specified - Leased Aircraft with explanation.

A.7 DATA RELIABILITY:

Considering the above approach of delay computation and classification which has been mentioned in the previous sections in details and the experience seen in coding as appeared in delay messages and delay discrepancy reports it confirms that the data is reliable. No doubt the way the data is constructed, in which a professional methodology according to policy procedure is established by airline management to ensure high service standards.

System Airport Services review the delay codes annually. They introduce new or revisions to the delay codes with their applications and explanations. These revisions or additions are based on the experiences that the specialists working in System Airport Services practiced on daily basis with delays. System Airport Services issue delay codes in a form of a little booklet that enhance the users to refer back in case of a delay occurrence and in case of any doubt in classification process.

The methodology of delay codes allocation which has been mentioned in Section 1.5 is also to improve the quality of the delay data and its reliability for further studies.

A.8 CONCLUSIONS:

This chapter introduced Saudia policy for punctuality management as extracted from Saudia Marketing and Ground Services Manual. Definitions of delays, minimum turn-around time and delivery time have been viewed. Computation of delays for originating, turn-around, through flights and others have been introduced with examples. Also in this appendix it is illustrated the approach of construction of delay data and explained the background of the data collected for the statistical analysis and delay distribution estimation.

APPENDIX (B)

SAMPLE OF SPSS/PC+ /SAS PROGRAMS AND WEIBULL ESTIMATION

In this appendix, a list of the major SPSS PC+ source programs used for the delay statistical analysis in chapter (3) are listed in section B.1. Section B.2 shows few general delay distributions for different categories. Section B.3 explains the procedure used for estimating the WEIBULL distribution three parameters used in chapter (4) developed by SEN AND PRABHASHANKER (57). Section B.4 shows a list of the major SAS source programs developed for the passengers attitude survey analysis.

(B.1) SPSS PC+ SOURCE PROGRAMS:

B.1.1) SPSS SOURCE CODE FOR DELAY ANALYSIS

This program is an spss source code program which is designed to produce the overall spss system file for delays and delays data.

```
DATA LIST FILE='\\DATA\\ANN86.TXT'
  /DAY 2-3 MONTH 5-6 YEAR 8-9 FLTNO 13-16
  SECTOR 21-28 (A) ACT 31-35 (A)
  TN 39-40 (A) DCODE1 45-46 DTIME1 49-53 (2).
  ORIG 21-23 (A) DEST 26-28 (A) ACT 31-35 (A).
  DCODE2 58-59 DTIME2 62-66 (2).

VARIABLE LABELS DAY 'DAY OF DELAY '/
  MONTH 'MONTH OF DELAY'/
  YEAR 'YEAR OF DELAY'/
  ORIG 'CITY OF ORIGIN'/
  DEST 'CITY OF DESTINATION'/
  ACT 'AIRCRAFT TYPE'/
  TN 'TAIL NUMBER'/
  DCODE1 'DELAY CODE 1'/
  DTIME1 'DELAY TIME 1'.

VALUE LABELS DCODE1
  01 '1 INDIRECT DELAY'
  02 '1 UNCLASSIFIED'
  03 '1 PENDING'
  04 '1 TIME GAINED'
  05 '1 TIME LOST'
  06 '1 AIRCRAFT RETURNED FROM TAXIWAY'
```

```
07 '1 AIRCRAFT ABORTED TAKE-OFF'
08 '1 AIRCRAFT RETURNED FROM FLIGHT'
09 '1 EQUIPMENT SHORTAGE'
10 '2 DAMAGE'
11 '2 LATE CHECK-IN AFTER DEADLINE'
12 '2 LATE CHECK-IN - CONGESTION'
13 '2 CHECK-IN ERROR'
14 '2 OVERSALES - BOOKING ERROR'
15 '2 BOARDING'
16 '2 COMMERCIAL PUBLICITY OR PAX
    VEN,ILLNESS,DEATH'
17 '2 CATERING BORDER-LATE OR INCORRECT'
18 '2 BAGGAGE HANDLING'
20 '1 TURN AROUND - LATE ARRIVAL /MARKETING '
21 '2 DOCUMENTATION ERRORS, ETC'
22 '2 LATE POSITIONING OF CARGO'
23 '2 SALES DECISION'
24 '2 INADEQUATE PACKING'
25 '2 OVERSALES BOOKING ERRORS'
26 '2 INCORRECT BUILD-UP OF ULD'
31 '2 AIRCRAFT DOCUMENTATION'
32 '2 LOADING OR UNLOADING'
33 '2 LOADING EQUIPMENT'
35 '2 AIRCRAFT CLEANING'
37 '2 CATERING - LATE DELIVERY'
38 '2 LACK OF ULD OR SERVICEABILITY'
63 '2 LATE CABIN CREW BOARDING'
67 '2 CABIN CREW SHORTAGE'
68 '2 CABIN CREW SPECIAL REQUEST'
34 '2 SERVICING EQUIPMENT '
39 '3 MAINTENANCE EQUIPMENT/SERVICING EQUIPMENT'
40 '1 TURN AROUND - LATE ARRIVAL /MAINTENANCE'
41 '3 AIRCRAFT DEFECTS - DELAY DUE TO TECH
    PROBLEM'
42 '3 SCHEDULED MAINTENANCE - LATE RELEASE FOR
    SVC'
43 '3 NON-SCHEDULED MAINTENANCE'
46 '3 AIRCRAFT CHANGE'
47 '3 DAMAGE'
48 '3 PERSONNEL'
49 '3 MAINTENANCE ROUTING'
30 '1 TURN AROUND - LATE ARRIVAL /MATERIAL
    MANAGEMENT'
36 '4 FUELING OR DEFUELING'
44 '4 SPARE PARTS'
45 '4 AOG SPARES, TO BE CARRIED TO ANOTHER
    STATION'
50 '1 LATE ARRIVAL - TURN AROUND /AUTOMATION
    SYSTEM'
51 '5 DAMAGE TO AIRCRAFT'
55 '5 AUTOMATED EQUIPMENT FAILURE - DEPARTURE
    CONTROL'
56 '5 AUTOMATED EQUIPMENT FAILURE - CARGO
    PREPAIRATION'
```

57 '5 AUTOMATED EQUIPMENT FAILURE - FLIGHT PLAN'
58 '5 AUTOMATED EQUIPMENT FAILURE - OTHER SYSTEMS'
60 '1 TURN AROUND - LATE ARRIVAL /FLIGHT
OPERATIONS'
61 '6 FLIGHT PLAN, FLIGHT DOCUMENTATION'
62 '6 OPERATIONAL REQUIREMENTS'
64 '6 LATE DECK CREW BOARDING OR DEPARTURE
PROCEDURE'
65 '6 FLIGHT DECK CREW SPECIAL REQUEST'
66 '6 MOVEMENT CONTROL'
68 '6 PERSONNEL - FLIGHT OPERATIONS'
69 '6 OPERATIONS PERSONNEL'
70 '1 LATE ARRIVAL - TURN AROUND /WEATHER'
71 '7 DEPARTURE STATION'
72 '7 DESTINATION STATION'
73 '7 ENROUTE OR ALTERNATE'
75 '7 DE-ICING & DESNOWING OF AIRCRAFT'
76 '7 REMOVAL OF SNOW, ICE, WATER AND SAND FROM
AIRPORT'
77 '7 GROUND HANDLING IMPAIRED BY ADVERSE WEATHER
CONDN'
80 '1 LATE ARRIVAL - TURN AROUND /GOVERNMENT'
81 '6 AIR TRAFFIC SERVICES'
82 '2 SECURITY'
83 '2 IMMIGRATION, CUSTOMS, HEALTH'
84 '3 AIRPORT FACILITIES'
27 '8 INCORRECT MAIL DOCUMENTATION'
28 '8 LATE POSITIONING OF MAIL'
29 '8 LATE ACCEPTANCE OF MAIL'
85 '8 RESTRICTIONS'
86 '8 AIRPORT CLOSED'
87 '8 NO GATE/STAND AVAILABLE'
88 '8 OPERATIONAL LIMITATION AT DESTINATION'
90 '1 LATE ARRIVAL - TURN AROUND /AIRPORT CLOSED'
96 '6 INDUSTRIAL ACTION WITH OWN AIRLINE'
97 '9 INDUSTRIAL ACTION WITHIN OWN AIRLINE'
98 '9 INDUSTRIAL ACTION OUTSIDE OWN AIRLINE'
99 '9 NOT ELSEWHERE CLASSIFIED'.

SET SCREEN=OFF/LISTING='DELAY1.LIS'/WIDTH=132.

FREQUENCIES VARIABLES=Dcode1 ACT TN ORIG
/STATISTICS = DEF.

CROSSTABS TABLES=Dcode1 BY ACT TN ORIG DAY MONTH YEAR
/OPTIONS = 3 4 5.

SAVE OUTFILE='\\DELAY\\DELAY1.SYS'.

B.1.2) SPSS SOURCE CODE FOR AIRLINE INTERNAL USE (AIU)

```
SET SCREEN=OFF/LISTING='DAIU.LIS'/WIDTH=132.
SELECT IF (DCODE1 = 01 OR DCODE1 = 02 OR DCODE1 = 03 OR DCODE1 = 04
          OR DCODE1 = 05 OR DCODE1 = 06 OR DCODE1 = 07 OR DCODE1 = 08
          OR DCODE1 = 09 ).
FREQUENCIES VARIABLES=DCODE1 ACT
          /STATISTICS=DEF.
CROSSTABS TABLES=DCODE1 BY ACT
          /OPTIONS=3 4 5.
MEANS TABLES=DTIME1 BY DCODE1/ OPTIONS=6 10.

PLOT      /FORMAT=regression/
          TITLE 'ALL CATEGORIES OF AIRLINE INTERNAL USAGE
          DELAYS'/
          VERTICAL='DELAY PERIOD IN HOURS'/
          HORIZONTAL='DAY OF DELAY'/
          PLOT=DTIME1 WITH DAY BY DCODE1.
* SAVE OUTFILE='\\DELAY\\DAIU.SYS'.
```

B.1.3) SPSS SOURCE CODE FOR MARKETING (MKT)

```
SET SCREEN=OFF/LISTING='DMKT.LIS'/WIDTH=132.
SELECT IF (DCODE1 = 10 OR DCODE1 = 11 OR DCODE1 = 12 OR DCODE1 = 13
          OR DCODE1 = 14 OR DCODE1 = 15 OR DCODE1 = 16 OR DCODE1 = 17
          OR DCODE1 = 18 OR DCODE1 = 20 OR DCODE1 = 21 OR DCODE1 = 22
          OR DCODE1 = 23 OR DCODE1 = 24 OR DCODE1 = 25 OR DCODE1 = 31
          OR DCODE1 = 32 OR DCODE1 = 33 OR DCODE1 = 35 OR DCODE1 = 37
          OR DCODE1 = 63 OR DCODE1 = 67 OR DCODE1 = 68).

FREQUENCIES VARIABLES=DCODE1 ACT
          /STATISTICS=DEF.

CROSSTABS TABLES=DCODE1 BY ACT
          /OPTIONS=3 4 5.

MEANS TABLES=DTIME1 BY DCODE1/ OPTIONS=6 10.

PLOT      /FORMAT=regression/
          TITLE 'ALL CATEGORIES OF MARKETTING DELAYS'/
          VERTICAL='DELAY PERIOD IN HOURS'/
          HORIZONTAL='DAY OF DELAY'/
          PLOT=DTIME1 WITH DAY BY DCODE1.
* SAVE OUTFILE='\\DELAY\\DMKT.SYS'.
```


B.1.4) SPSS SOURCE CODE FOR DELAY MEANS ANALYSIS

The source program below is a delay analysis program which determine the delay division of all delays exist in the schedule. Then means of these delays and delay time are determined and categorized by different parameters such as aircraft, month and delay type.

```
SET SCREEN=OFF/LISTING='SECTOR.LIS'/WIDTH=132.
```

```
COMPUTE DELDIV=DCODE1.
```

```
RECODE DELDIV    (01 THRU 09,20,30,40,50,60,70,80,90=1)
(10 THRU 18,21 THRU 26,31 THRU 35,37,38,63,67,68,82,83=2)
                  (39,41 THRU 43,46 THRU 49,84=3)
                  (36,44,45=4)
                  (51,55 THRU 58=5)
                  (61,62,64 THRU 66,69,81,96=6)
                  (71 THRU 73,75 THRU 77=7)
                  (85 THRU 88,27 THRU 29=8)
                  (97 THRU 99,52,53,54,79=9).
```

```
VALUE LABELS DELDIV
```

```
1 'AIRLINE INTERNAL USE'
2 'MARKETING'
4 'MATERIAL MANAGEMENT'
3 'TECHNICAL & AIRCRAFT MOVEMENT'
5 'SYSTEM DELAY'
6 'FLIGHT OPERATIONS'
7 'WEATHER'
8 'AIRPORT AND GOVERNMENT AUTHORITY'
9 'MISCELLANEOUS'.
```

```
VALUE LABELS MONTH
```

```
01 'JAN'
02 'FEB'
03 'MAR'
04 'APR'
05 'MAY'
06 'JUN'
07 'JUL'
08 'AUG'
09 'SEP'
10 'OCT'
11 'NOV'
12 'DEC'.
```

```
SET LISTING='DMEAN5.LIS'.
```

```
MEANS TABLES=DTIME1 BY SECTOR/OPTIONS=6.
```

```
MEANS TABLES=DTIME1 BY FLTNO/OPTIONS=6.

MEANS TABLES=DTIME1 BY DCODE1 BY MONTH /OPTIONS=6.

MEANS TABLES=DTIME1 BY ACT TN ORIG BY MONTH /OPTIONS=6.

MEANS TABLES=DTIME1 BY DELDIV BY MONTH/OPTIONS=6.

MEANS TABLES=DTIME1 BY deldiv BY DCODE1/OPTIONS=6.

MEANS TABLES=DTIME1 BY DCODE1 /OPTIONS=6.

FREQUENCIES VARIABLES=DELDIV DCODE1
      /STATISTICS=DEF
      /HISTOGRAM=MINIMUM(01) MAXIMUM(99) INCREMENT(1).

SAVE OUTFILE='\\DELAY\\DMEAN2.SYS'.
```

B.1.5) SPSS SOURCE CODE FOR FLOGHT OPERATIONS **DELAY ANALYSIS (OPS)**

```
SET SCREEN=OFF/LISTING='DOPS.LIS'/WIDTH=132.

SELECT IF (DCODE1 = 60 OR DCODE1 = 61 OR DCODE1 = 62 OR DCODE1 = 64
      OR DCODE1 = 65 OR DCODE1 = 66 OR DCODE1 = 68).

FREQUENCIES VARIABLES=DCODE1 ACT
      /STATISTICS=DEF.

CROSSTABS TABLES=DCODE1 BY ACT
      /OPTIONS=3 4 5.

MEANS TABLES=DTIME1 BY DCODE1/ OPTIONS=6 10.

PLOT     /FORMAT=regression/
      TITLE 'ALL CATEGORIES OF FLIGHT OPERATION DELAYS'/
      VERTICAL='DELAY PERIOD IN HOURS'/
      HORIZONTAL='DAY OF DELAY'/
      PLOT=DTIME1 WITH DAY BY DCODE1.

SAVE OUTFILE='\\DELAY\\DOPS.SYS'.
```

**B.1.6) SPSS SOURCE CODE FOR TECHNICAL DELAY
ANALYSIS (TECH)**

```
SET SCREEN=OFF/LISTING='DTECH.LIS'/WIDTH=132.
SELECT IF (DCODE1 = 34 OR DCODE1 = 40 OR DCODE1 = 41 OR DCODE1 = 42
          OR DCODE1 = 43 OR DCODE1 = 46 OR DCODE1 = 47 OR DCODE1 = 48
          OR DCODE1 = 49 ).

FREQUENCIES VARIABLES=DCODE1 ACT
          /STATISTICS=DEF.

CROSSTABS TABLES=DCODE1 BY ACT
          /OPTIONS=3 4 5.

MEANS TABLES=DTIME1 BY DCODE1/ OPTIONS=6 10.

PLOT      /FORMAT=regression/
          TITLE 'ALL CATEGORIES OF TECHNICAL DELAYS'/
          VERTICAL='DELAY PERIOD IN HOURS'/
          HORIZONTAL='DAY OF DELAY'/
          PLOT=DTIME1 WITH DAY BY DCODE1.
SAVE OUTFILE='\\DELAY\\DTECH.SYS'.
```

B.1.7) SPSS SOURCE CODE FOR DEPARTURE ANALYSIS

The following file is a spss source code which is written to read the number of flight departures for each citypair using aircraft type.

```
DATA LIST FILE='\\Data\\DEPS.TXT'
          /YEAR 1-2 MONTH 3-4 ORIG 5-7 (A) TN 11-12 (A) DEPS 16-17.

VARIABLE LABELS YEAR 'YEAR OF DEPARTURE'/
          MONTH 'MONTH OF DEPARTURE'/
          TN 'TAIL NUMBER'/
          ORIG 'CITY OF ORIGIN'/
          DEPS 'NUMBER OF DEPARTURES'/.

VALUE LABELS MONTH
          01 'JAN'
          02 'FEB'
          03 'MAR'
          04 'APR'
          05 'MAY'
          06 'JUN'
          07 'JUL'
          08 'AUG'
          09 'SEP'
```

```

10 'OCT'
11 'NOV'
12 'DEC'.

COMPUTE ACT=TN.

RECODE ACT      ('JA','JB','JC','JD','JE','JF','JG','JH','JI'      , 'JJ','JK'      =
'AB')

('CC','CD','CG','CI','CJ' = 'B0')
('GA','GB','GC','GD','GE','GF','GG','GH','GI','GJ',
'GK','GL','GM','GN','GO','GP','GQ','GR','GS'='B3')
('IA','IB','IC','ID','IE','IG','IH','II' = 'B4')
('IK','IL','IM','IN','IO','IP','IQ','IR','IS','IT'
='BT')
('IF','IJ' = 'BS')
('HA','HB','HC','HD','HE','HF','HG','HH','HI','HJ',
'HL','HM','HN','HO','HP','HQ','HR'='L1')
('BM','BN' = 'F2').

VALUE LABELS ACT

'AB' 'AB300'
'B0' 'B707'
'B3' 'B737'
'B4' 'B747'
'BT' 'B747-3'
'BS' 'B747-SP'
'L1' 'L1011'
'F2' 'F-28'.

SAVE OUTFILE='\\DELAY\\DEPS.SYS'.

```

B.1.8) SPSS SOURCE CODE FOR DELAY/DEPARTURE ANALYSIS

The program below explained the departure analysis by aircraft type and by month.

```

SET SCREEN=OFF/LISTING='DEPS2.LIS'/WIDTH=132.
GET FILE = '\\DELAY\\DEPS.SYS'.
MEANS TABLES=DEPS BY ACT BY MONTH/OPTIONS = 6 12.

```

Similar analysis is done but for delay analysis. So tables are generated illustrates the delay time by aircraft type and by month of delay.

```

SET SCREEN=OFF/LISTING='DEPS1.LIS'/WIDTH=132.
GET FILE = '\\DELAY\\DELAY.SYS'.
MEANS TABLES=DTIME1 BY ACT BY MONTH/OPTIONS = 6 12.

```

(B.2) PROCEDURE FOR ESTIMATING THE WEIBULL DISTRIBUTION PARAMETERS USING THE NOMOGRAPH

As discussed earlier in chapter (4) in the contents of weibull distribution estimation that the Weibull Probability Density Function is defined in terms of its parameters B, and o as appears in equation below. The following definition is a function of parameters a1, a2 and a3 as defined in (SEN and PRABHASHANKER (57)).

$$f(x) = (a1-a2) \{(x-a3)/a2\}^{a1-1} \exp [-\{(x-a3)/a2\}^{a1}]$$

where

a1 = shape parameters,

a2 = scale parameters,

a3 = Location parameter.

f(x) is valid for a1 and a2 > 0 and f(x)=0 if x < a3.

Estimating the population parameters from the sample data for many distributions could be quite tedious. In many cases the maximum likelihood (ML) estimates provide more efficient estimations than the simple method of movements (MM). However, the method of moment could be useful and preferable under certain conditions. This is particularly true for certain ranges of the parameter values in case of the Weibull distribution.

The use of ML estimates was generally avoided by engineers until recently, as it results in a system of non-linear equations not easy to solve. The situation is further complicated by the intersinic constraints imposed on the parameters. Considerable difficulty is encountered in fitting Weibull distribution and have suggested methods for parameter estimations.

The Weibull distribution parameters cannot be expressed in terms of the lower moments by simple functions. SEN and PRABHASHANKER developed a

simple nomograph from which the three parameters could be estimated with reasonable accuracy. Though as not efficient as ML estimates but as demonstrated by SEN and PRABHASHANKER in many cases the nomograph is quite adequate. **The figure** below shows the nomograph used for estimation of sample distribution function for Weibull distribution function. The method of nomograph construction is illustrated in the appendix of the SEN and PRABHASHANKER (57).

The **estimation approach** focuses on estimating the three parameters values a_1 , a_2 and a_3 . To determine these values, the sample estimate of $(\beta_1)^{0.5}$, σ and μ have to be evaluated and used as the starting points in the nomograph. Then update distribution parameters and determine the fitting accuracy by calculating the error and error percentage for the actual distribution. Starting points are defined as follows:

μ = Sample Mean

σ = Sample standard deviation

$(\beta_1)^{0.5}$ = Sample estimate of the standardized third moment.

The mathematical derivation of these sample parameters are defined as :

$$\mu = d + b m_1 ,$$

$$\sigma = \{b^2 (m_2 - m_1)^2\}^{0.5} ,$$

$$\text{and } (\beta_1)^{0.5} = (m_3 / m_2)^{1.5}$$

where

b = the interval,

d = the most popular frequency interval,

m_r is the r th moment around the mean

$$m_r = [\sum \{f_i (Z_i)^r\}] / n$$

where

$$Z_i = (x_i - d)/b$$

B.2.2 General Procedure for estimating the distribution parameters from the nomograph:

- 1) Use scales 1a and 1b and curves 3a or 3b depending on values of $(\beta 1)^{0.5}$. Make $(\beta 1)^{0.5}$ in scale 1a and draw the lines POP1 through the curve 3a. Read a1 from scale 2a.
- 2) Locate σ on scale 4, joint σ and a1 and extend to scale 6, read a2 from scale 6.
- 3) Transfer a1 to scale 2b. Join a1 (scale 2b) to σ (Scale 4) and extend to scale 5. Read the values of m1 - a3 on scale 5.

Estimation of the general delay distribution:

The purpose is to demonstrate the approach for estimation of general delay frequency distribution as Weibull distribution function. It appears in figure 4.1 the general delay frequency distribution function with mean = 0.989 and variance = 1.15. The three sample parameters (μ , σ and $(\beta 1)^{0.5}$) are calculated according to the formulas defined earlier by means of Lotus 123 spread sheet. The following are the values determined:

$$\mu = 0.9855$$

$$\sigma = 1.0309$$

$$(\beta 1)^{0.5} = 6.6571$$

Using these parameters to determine the three Weibull parameter a_1 , a_2 and a_3 from the nomograph appears in Figure 4.5.

Estimating the parameters from the nomograph:

- 1) Use scales 1a and 1b and curves 3a or 3b depending on values of $(\beta_1)^{0.5}$. In this case $(\beta_1)^{0.5} = 6.657$, make $(\beta_1)^{0.5}$ in scale 1a and draw the lines POP1 through the curve 3a. Read a_1 from scale 2a, $a_1 = 0.50$.
- 2) Locate σ on scale 4, joint o and a_1 and extend to scale 6, read a_2 from scale 6. $a_2 = 0.38$
- 3) Transfer a_1 to scale 2b. Join a_1 (scale 2b) to σ (Scale 4) and extend to scale 5. Read the values of $m_1 - a_3$ on scale 5. $M_1 - a_3 = 0.48$

$$0.9855 - 0.48 = a_3$$

$$a_3 = 0.50$$

Using these values as a basis for an interactive procedure in fitting the distribution by numerical monitoring of the error and percentage error from the actual distribution. As mentioned earlier in this section, finding the synthetic distribution is a tedious activity, the estimated parameters formulated by SEN and PRABHASHANKER a_1 , a_2 and a_3 could not be reflected easily in the distribution. In other words when actual updating values for scale or location the PROBABILITY DISTRIBUTION FUNCTION changes its shape rather than changing its scale or location.

However, after number of iterations the parameters of Weibull distribution function are estimated as follows:

a_1	=	0.75
a_2	=	0.75
a_3	=	0.05
σ	=	0.9855
μ	=	1.039

(B.3) SAS SOURCE PROGRAMS FOR THE PASSENGERS SURVEY ANALYSIS

```

//PLRA001S JOB (211PLR,000000,508),'HAIMI ',MSGCLASS=X,
//      NOTIFY=PLRA001
//*MAIN CLASS=B
//SAS1 EXEC SAS
//IN1 DD DSN=PLR99.PASURV.DATA,DISP=SHR
//*IN1 DD DSN=PLRA001.ESAM2.DATA,DISP=SHR
//SAS.SYSIN DD *
DATA A1;
  INPUT IN1;
  INPUT SUR 1-4 FLT 6-8 SCLASS$ 9 DEST$ 10-12 FLTMAD 15-16 FLTDLY 18-19
        SAT 21 DLY 33 COMP 34-38 INFUL 40 CXL 42
        COMP1 34 COMP2 35 COMP3 36 COMP4 37 COMP5 38
        NAT 44 PURPOS 46 INCOME 48
        IMPACT1 23 IMPACT2 25 IMPACT3 27 IMPACT4 29 IMPACT5 31;
*;
IF FLTMAD > 0 THEN OTP=(FLTMAD-FLTDLY)/FLTMAD;
IF OTP => .95 AND OTP <= 1.0 THEN DR =1;
IF OTP => .90 AND OTP < .95 THEN DR =2;
IF OTP => .85 AND OTP < .90 THEN DR =3;
IF OTP => .80 AND OTP < .85 THEN DR =4;
IF OTP => .70 AND OTP < .80 THEN DR =5;
IF OTP <= .70 THEN DR =6;
*;
IF FLT => 400 THEN DIV ='DOM';
  ELSE DIV ='INT';
PROC SORT;
  BY DIV;
PROC FORMAT;
  VALUE $CLASS_F 1='FIRST CLASS' 3='ECONOMY CLASS'
                2='HORIZON CLASS';
  VALUE IMPC_F 1='NO IMPACT'
               2='V. SLIGHT IMPACT'
               3='SLIGHT IMPACT'
               4='SERIOUS IMPACT'
               5='V. SERIOUS IMPACT';
  VALUE SAT_F 1='NOT SATISFY'
              2='SATISFY' 3='HIGHLY SATISFY';
  VALUE DR_F 1='95-100 %' 2='90-95 %' 3='85-90 %' 4='80-85 %'
             5='70-80 %' 6='< 70 %';
  VALUE PURPS_F 1='BUSINESS' 2='LEISURE/VACATION' 3='OTHERS';
  VALUE NAT_F 1='ARABS' 3='ASIANS' 2='WESTERNERS' 4='OTHERS';
  VALUE DLY_F 1='STAY WAITING UNTIL FLT READY'
              2='COME FOR THE NEXT AVAILABLE'
              3='CANCEL/FIND ALTERNATIVE'
              4='CANCEL THIS TRIP';
  VALUE COMP_F 1='PROVIDE FOOD/BEVERAGES'
               2='PROVIDE TEL SRVCS'
               3='FAMILY/MOTHERCARE FACILITIES'
               4='FINANCIAL COMPENSATION'
               5='OTHERS';
  VALUE INFUL_F 1='NO INFLUENCE'
                2='SOME INFLUENCE'
                3='GREAT INFLUENCE';
  VALUE CXL_F 1='COME FOR THE NEXT AVAILABE FLIGHT'
              2='FIND ALTERNATIVE (OAL/CAR)'
              3='CANCEL THIS TRIP';
  VALUE INCOME_F 1='BELOW SR 5000'
                 2='SR 5000-10000'
                 3='SR 10000-15000'
                 4='MORE THAN 15000';
* PROC PRINT LABEL;

```

```

* VAR P1A--P1C H1;
* FORMAT H1 NAT_F. P1A--P1C RATE_F.;
*
* THIS IS THE FREQUENCY PROCEDURE;
*
PROC FREQ;
* TABLES (SAT DLY COMP1--COMP5 INFUL CXL) * (NAT PURPOS INCOME) ;
* TABLES (IMPACT1--IMPACT5 OTP DR) * (NAT PURPOS INCOME) ;
* TABLES DLY * IMPACT1--IMPACT5;
* TABLES DLY * DEST;
* TABLES DLY * IMPACT1--IMPACT5 ;
TABLES DLY * NAT;
BY DIV;
FORMAT IMPACT IMPC_F.
        IMPACT1--IMPACT5 IMPC_F.
        SAT SAT_F.
        DLY DLY_F.
        CXL CXL_F.
        COMP1--COMP5 COMP_F.
        INFUL INFUL_F.
        PURPOS PURPS_F.
        NAT NAT_F.
        DR DR_F.
        INCOME INCOME_F.
        SCLASS $CLASS_F.;
LABEL  FLTMAD = 'NO. OF FLIGHTS MADE DURING 12 MONTHES'
        FLTDLY = 'NO. OF FLIGHTS DELAYED MORE THAN 30 MIN'
        IMPACT = 'OVERALL IMPACT OF DELAY '
        IMPACT1 = 'IMPACT OF .5 HR DELAY '
        IMPACT2 = 'IMPACT OF 1 HR DELAY '
        IMPACT3 = 'IMPACT OF 2 HR DELAY '
        IMPACT4 = 'IMPACT OF 4 HR DELAY '
        IMPACT5 = 'IMPACT OF 6 HR DELAY '
        DLY = 'YOUR POSSIBLE ACTION INCASE OF DELAY (V.SERIOUS DEL)'
        CXL = 'YOUR POSSIBLE ACTION INCASE OF CANCELLATION'
        SAT = 'SATISFY WITH SV PUNCTUALITY'
        COMP = 'SUITABLE COMPENSATION IF FLT DELAYED FOR 2 HRS'
        INFUL = 'FUTURE AIRLINE CHOICE INFLUENCE'
        NAT = 'NATIONALITY'
        OTP = 'PAX EXPERIENCE OTP'
        DR = 'SUMMARY EXPERIENCE OTP '
        PURPOS = 'PURPOSE OF THE TRIP'
        INCOME = 'MONTHLY INCOME GROUP';
TITLE1 PASSENGER ATTITUDE SURVEY TOWARDS PUNCTUALITY;
TITLE2 GENERAL ANALYSIS;
TITLE3 JUNE 1989;

```

APPENDIX (C)

SAMPLE OF AIRCRAFT ROT

MAY19 1810	45	45
:	:	1:00
0410 JED		
MAY19 1840		30
:	:	
0441 RUH		
MAY19 1850		
:	:	
Z 500		600
END OF REPORT		

	35	DHA	00	10
1:05				1:10
:	:	:	:	:
00				
	RUH			
10				
:	:	:	:	:
	0487			0441
ELQ	18	55	20	
	1:45	HAS		1:30
:	:	:	:	:
1400	1500	1600		1700

APPENDIX (A)
SKDMOD PROGRAM LIST

PREAMBLE '' Schedule Punctuality Simulation Model

```
''
'' Airline sechedule simulation to determine the punctuality
'' level in the sechedule plan. Different management
'' strategies and policies are simulated and measure
'' their impact on punctuality
```

Normally mode is undefined

TEMPORARY ENTITIES

```
every flight has
  a fl.id,
  a fl.skd.dep,
  a fl.skd.arr,
  a fl.act.dep,
  a fl.act.arr,
  a fl.sd,
  a fl.sa,
  a fl.ad,
  a fl.aa,
  a fl.bt,
  a fl.blk.time,
  a fl.orig.delay,
  a fl.react.delay,
  a fl.total.delay,
  a fl.o.d,
  a fl.r.d,
  a fl.t.d,
  a fl.ac.plan.id,
  a fl.ac.act.id,
  a fl.ac.request.time,
  a fl.ac.arr.del,
  a fl.holding.time,
  a fl.orign,
  a fl.dest,
  a fl.seq
and belongs to a fl.queue
and belongs to a fl.list
```

```
define scaler,fl.id    as an integer variable
define fl.sd           as an integer variable
define fl.sa           as an integer variable
define fl.ad           as an integer variable
define fl.aa           as an integer variable
define fl.bt           as an integer variable
define fl.o.d          as an integer variable
define fl.r.d          as an integer variable
define fl.t.d          as an integer variable
define fl.seq          as an integer variable
```

```
define fl.skd.dep      as a real variable
define fl.skd.arr      as a real variable
define fl.act.dep      as a real variable
define fl.act.arr      as a real variable
define fl.blk.time     as a real variable
define fl.orign        as a text variable
define fl.dest         as a text variable
define fl.orig.delay   as a real variable
define fl.react.delay  as a real variable
define fl.total.delay  as a real variable
define end.time        as a real variable
define fl.ac.plan.id   as a text variable
define fl.ac.act.id    as a text variable
define fl.ac.request.time as a real variable
define fl.ac.arr.del   as a real variable
define fl.holding.time as a real variable
```

```
define no.of.flights as an integer variable
```

```
the system owns the fl.queue
the system owns the fl.list
''define fl.queue as a set ranked by low fl.sd
define fl.queue as a FIFO set
after filing in fl.queue call trigger.assignment
```

every AIRCRAFT has

```
  a ac.id,
  a ac.status,
  a ac.code,
  a ac.location,
  a ac.flights.flown,
  a ac.fl.id,
  a ac.as.flag,
  a ac.otp,
  a ac.blk.hrs
and belongs to a ac.idle
and belongs to a ac.list
```

```
the system owns the ac.list
the system owns the ac.idle
```

```
define ac.blk.hrs      as a real variable
define ac.otp          as a real variable
define ac.flights.flown as an integer variable
define ac.fl.id        as an integer variable
define ac.id           as a text variable
define ac.as.flag      as a text variable
define ac.status       as a text variable
define ac.code         as a text variable
define ac.location     as a text variable
```

```
define no.of.aircraft  as an integer variable
```

```
the system has a mean.del.time,
  a MDAS,
  a min.ground.time,
```


and a max.ground.time

```
define max.ground.time as a real variable
define min.ground.time as a real variable
define mean.del.time   as a real variable
define hours           as an integer variable
define minutes         as a real variable
define loc.flight      as a pointer variable
define MDAS            as a real variable
```

PROCESSES

```
every assign.ac.to.flt has
  a as.flight,
  a as.aircraft,
  a as.priority
  define as.flight,
    as.aircraft as a pointer variable
  define as.priority as an integer variable
```

break assign.ac.to.flt ties by low as.priority

```
every skedule has
  a sk.flight,
  a sk.aircraft
  define sk.flight,
    sk.aircraft as pointer variables
```

" tallys for day stats ...

```
tally day.orig.time.delay as the sum of d.orig.delays
tally day.act.time.delay as the sum of d.react.delays
tally day.avg.all.delay as the mean, day.all.time.delay as the sum, day.delays as the number,
day.min.all.delay as the minimum, day.max.all.delay as the maximum of d.all.delays
tally day.avg.serious.delay as the mean, day.serious.time.delay as the sum, day.serious.delays as the
number, day.min.serious.delay as the minimum, day.max.serious.delay as the maximum of d.serious.delays
tally day.blk.time as the sum of d.blk.time
tally day.spare.ac.bhs as the sum of d.spare.ac.bhs
```

```
define d.orig.delays      as a real variable
define d.react.delays     as a real variable
define d.all.delays       as a real variable
define d.blk.time         as a real variable
define d.spare.ac.bhs     as a real variable
define d.serious.delays   as a real variable
```

" tallys for skd stats...

```
tally skd.orig.time.delay as the sum of s.orig.delays
tally skd.act.time.delay as the sum of s.react.delays
tally skd.avg.all.delay as the mean, skd.all.time.delay as the sum,
  skd.delays as the number, skd.min.all.delay as the minimum,
  skd.max.all.delay as the maximum of s.all.delays
tally skd.avg.serious.delay as the mean, skd.serious.time.delay
  as the sum, skd.serious.delays as the number, skd.min.serious.delay
  as the minimum, skd.max.serious.delay as the maximum of s.serious.delays
tally skd.blk.time as the sum of s.blk.time
tally skd.depatures as the sum of no.of.flights
```

tally skd.spare.ac.bhs as the sum of s.spare.ac.bhs

```

define s.orig.delays      as a real variable
define s.react.delays     as a real variable
define s.all.delays       as a real variable
define s.blk.time        as a real variable
define s.serious.delays   as a real variable
define s.spare.ac.bhs    as a real variable

```

END '' end preamble

MAIN

```

define .flight,
    .aircraft
    as pointer variables
define .days.simulated
    as an integer variable

```

```

call set.defaults
call menu

```

```

use unit 10 for output
lines.v = 0

```

print 2 lines thus

```

      FLT BLK  --SKEDULE--  --ACTUAL---  ----DELAYS----
ORIG DEST NUM TIME  AC DEP  ARR  AC DEP  ARR  ORIG  REACT ALL

```

```

while .days.simulated < end.time
do

```

```

    time.v = 0
    call initialise '' read flight and aircraft data
    start simulation
    until fl.queue is empty
    do
        remove the first .flight from fl.queue
    loop

```

```

until fl.list is empty
do
    remove the first .flight from fl.list
    destroy the flight called .flight
loop

```

call aircraft.report

```

until ac.idle is empty
do
    remove the first .aircraft from ac.idle
loop

```

```

until ac.list is empty
do
    remove the first .aircraft from ac.list
    destroy the aircraft called .aircraft

```

```

loop

add 1 to .days.simulated
print 1 line with .days.simulated thus
  Simulation Day = *
call day.performance.report

'' start a fresh day to all daily totals

reset totals of d.orig.delays,
               d.react.delays,
               d.blk.time,
               d.all.delays ,
               d.serious.delays

loop
call skd.performance.report

END '' end main
ROUTINE MENU
define CHOICE as an alpha variable
define DONE as a text variable

let DONE = "n"
call vbcolor.r(1)    '' blue text background
call vfcolor.r(15)   '' white text foreground
let lines.v = 0      '' turn off 55 lines/page

until DONE = "y"
do
  call vclears.r
  print 11 lines with
    mean.del.time,min.ground.time,max.ground.time,MDAS,end.time thus



---


Schedule Simulation Menu


---



Default values
Mean Delay Time = **.*** Hours
Min Ground Time = ***. * Minutes
Pln Ground Time = ***. * Minutes
M D A S Time = **. * Hours
Simulation Time = *** Day(s)

print 10 lines thus

1) Change the Mean Delay Time
2) Change the MIN Ground Time
3) Change the Planned Ground Time
4) Change the MDAS time
5) Change the Simulation Duration

R) Run the simulation
E) Exit the simulation

call vgotoxy.r(21,0)
write as "Enter your choice => ",+

```

```

call rcr.r
read CHOICE as A 1
call vgotoxy.r(21,0)
call vclearl.r

select case CHOICE

case "1"
  write as "Enter new mean delay time =>"+
  read mean.del.time
  if mean.del.time <= 0.0
    let mean.del.time = 0.001
  always

case "2"
  write as "Enter new MIN ground time =>"+
  read min.ground.time
  if min.ground.time < 0.0 and min.ground.time >= 90.0
    let min.ground.time = 50.0
  always

case "3"
  write as "Enter new planned ground time =>"+
  read max.ground.time
  if max.ground.time < 0.0 and max.ground.time >= 240.0
    let max.ground.time = 60.0
  always

case "4"
  write as "Enter new   M D A S   time =>"+
  read MDAS

case "5"
  write as "Enter new simulation time =>"+
  read end.time

case "R", "r"
  let DONE = "y"
case "E", "e", "X", "x"
  stop

default
endselect
loop
END '' routine to MENU

```

ROUTINE SET.DEFAULTS

```

'' let SCALER = 30          30 real sec per one hour
let min.ground.time = 30.0  '' minutes
let max.ground.time = 50.0  '' minutes
let end.time = 7            '' days
let mean.del.time = 1.000   '' hours

END '' routine to SET.DEFAULTS

```

ROUTINE INITIALISE

```
define i,j and hours as an integer variable
define minutes as a real variable

lines.v=0
use 10 for output

open 11 for input, name is "aircraft.dat"
use 11 for input
read no.of.aircraft  '' 7 ac's
start new card
for j = 1 to no.of.aircraft  ''each aircraft
do
create an aircraft
read ac.id,
    ac.location,
    ac.code,
    ac.status,
    ac.as.flag
start new card
file aircraft in ac.list
file aircraft in ac.idle
loop
close 11

open 12 for input, name is "flight.dat"
use 12 for input
read no.of.flights  '' 70 flights in all cycles
start new card
for i=1 to no.of.flights  '' each flight
do
create a flight
read fl.ac.plan.id,
    fl.seq,
    fl.orign,
    fl.dest,
    fl.sd,
    fl.sa,
    fl.id,
    fl.bt

hours = trunc.f(fl.sd/100)
minutes = fl.sd - hours*100
fl.skd.dep = hours/hours.v + minutes/minutes.v/hours.v
hours = trunc.f(fl.sa/100)
minutes = fl.sa - hours*100
fl.skd.arr = hours/hours.v + minutes/minutes.v/hours.v
hours = trunc.f(fl.bt/100)
minutes = fl.bt - hours*100
fl.blk.time = hours/hours.v + minutes/minutes.v/hours.v

fl.ac.act.id = "NONE"

file flight in fl.list
file flight in fl.queue

loop
```

```

        close 12
END ''initialise

```

```

ROUTINE trigger.assignment given loc.flight

```

```

define loc.flight as a pointer variable
fl.ac.request.time(loc.flight)= fl.skd.dep(loc.flight)
fl.holding.time(loc.flight) = fl.ac.request.time(loc.flight) - frac.f(time.v)
activate a assign.ac.to.flt given loc.flight in fl.holding.time(loc.flight) day

END ''

```

```

PROCESS assign.ac.to.flt

```

```

define loc.as as a pointer variable
define .ac as a pointer variable
define .fl as a pointer variable

```

```

loc.as = process.v

```

```

'' prioritise flt assignment as flt sequence
as.priority(loc.as) = fl.seq(as.flight(loc.as))

```

```

'START'

```

```

for every .ac in ac.idle
    with ac.code(.ac) = "ACTIVE"
    and ac.status(.ac) = "NOT.ASSIGNED"

```

```

do

```

```

    if ac.location(.ac) = fl.orign(as.flight(loc.as))
    then if ac.id(.ac) = fl.ac.plan.id(as.flight(loc.as))
        fl.ac.act.id(as.flight(loc.as)) = ac.id(.ac)
        ac.status(.ac) = "ASSIGNED"
        ac.fl.id(.ac) = fl.id(as.flight(loc.as))
        as.aircraft(loc.as)=.ac
    leave

```

```

    always

```

```

loop

```

```

if fl.ac.act.id(as.flight(loc.as)) = "NONE"
    wait 5 minutes
    add 5/minutes.v/hours.v to fl.ac.arr.del(as.flight(loc.as))
    if fl.ac.arr.del(as.flight(loc.as)) > MDAS/hours.v
        '' MDAS = max del to assign spare ac
        then if fl.orign(as.flight(loc.as)) = "RUH"
            go to 'REPLACE'
    always

```

```

    if fl.ac.arr.del(as.flight(loc.as)) > 20/hours.v
        '' send spare ac to serve this flight as if the flight
        '' is cancelled and replaced by this one time include
        '' ferry operations
        for every .ac in ac.idle
            with ac.code(.ac) = "SPARE"

```

```

and ac.status(.ac) = "NOT.ASSIGNED"
find the first case
if found
    ac.location(.ac) = fl.orign(as.flight(loc.as))
    go to 'REPLACE.AC'
always
    go to 'MESSAGE'

'MESSAGE'    print 1 line thus
===== WARNING : A/C NOT AVAILABLE =====
    print 1 line with fl.id(as.flight(loc.as)),
        fl.orign(as.flight(loc.as)),
        fl.dest(as.flight(loc.as)),
        time.v*hours.v,
        fl.ac.plan.id(as.flight(loc.as)),
        fl.ac.act.id(as.flight(loc.as)),
        as.priority(loc.as) thus
    *** **** **** ** ** ** ****

    for every .ac in ac.idle
    do
        print 1 line with ac.id(.ac),
            ac.status(.ac),
            ac.code(.ac),
            ac.location(.ac),
            ac.fl.id(.ac) thus
        ** ***** ***** **** **

    loop
    stop
    always
    go to 'START'
always
remove as.flight(loc.as) from fl.queue
go to 'ACTION'

'REPLACE'
for every .ac in ac.idle
    with ac.code(.ac) = "SPARE"
    and ac.status(.ac) = "NOT.ASSIGNED"
do
    if ac.location(.ac) = fl.orign(as.flight(loc.as))
        leave
    always
loop

'REPLACE.AC'

    fl.ac.act.id(as.flight(loc.as)) = ac.id(.ac)
    ac.status(.ac) = "ASSIGNED"
    ac.code(.ac) = "ACTIVE"
    ac.fl.id(.ac) = fl.id(as.flight(loc.as))
    as.aircraft(loc.as) = .ac

if fl.ac.act.id(as.flight(loc.as)) = "NONE"
''    wait 10 minutes
''    go to 'REPLACE'
    print 1 line thus

```



```

===== WARNING : SPARE A/C NOT AVAILABLE =====
stop
always

remove as.flight(loc.as) from fl.queue

'' check if old flights exist before update ac rec

    for every .fl in fl.queue
        with fl.ac.plan.id(.fl) = fl.ac.plan.id(as.flight(loc.as))
        do
            if fl.skd.dep(.fl) <= fl.skd.dep(as.flight(loc.as))
                go to 'FLIGHTS'
            always
        loop

'AIRCRAFT'
    '' UPDATE ac parameters

        for every .ac in ac.idle
            with ac.code(.ac) = "ACTIVE"
            '' and ac.status(.ac) = "NOT.ASSIGNED"

            do
                if ac.id(.ac) <> ac.id(as.aircraft(loc.as))
                    then if ac.id(.ac) = fl.ac.plan.id(as.flight(loc.as))
                        '' wait 2 hours
                        '' mean time to repair
                        ac.status(.ac) = "NOT.ASSIGNED"
                        ac.code(.ac) = "SPARE"
                        ''if ac.location(.ac) <> "RUH"
                        ''    wait 2 hours
                        '' always
                        ''ac.location(.ac) = "RUH"
                    always
                loop
            loop

'FLIGHTS'
    '' replace all turn around flts in ac cycle to the spare ac

    for every .fl in fl.queue
        with fl.ac.plan.id(.fl) = fl.ac.plan.id(as.flight(loc.as))
        do
            if .fl <> as.flight(loc.as)
                '' then if fl.seq(.fl) <> fl.seq(as.flight(loc.as))
                    then if fl.skd.dep(.fl) > fl.skd.dep(as.flight(loc.as))
                        fl.ac.plan.id(.fl) = ac.id(as.aircraft(loc.as))
                    always
            loop

'ACTION'

    activate a skedule given as.flight(loc.as), as.aircraft(loc.as) now

```

END

PROCESS SKEDULE

```
Define this.skedule as a pointer variable
Define this.flight as a pointer variable
Define this.aircraft as a pointer variable
Define disturbance as a real variable

this.skedule = process.v
this.flight = sk.flight(this.skedule)
this.aircraft = sk.aircraft(this.skedule)

    if frac.f(time.v) < fl.skd.dep(this.flight)
        wait (fl.skd.dep(this.flight)-frac.f(time.v)) days
    always

fl.react.delay(this.flight) = frac.f(time.v)-fl.skd.dep(this.flight)

d.react.delays = fl.react.delay(this.flight)  '' d = for day tallys
s.react.delays = d.react.delays              '' s = for skd tallys

disturbance = uniform.f (0,1,1)
    if disturbance < .85
        fl.orig.delay(this.flight) = 0
    else

'' log normal fun :(mean,std.dev,random.generator)

fl.orig.delay(this.flight) = log.normal.f(mean.del.time,1.0724,1)/hours.v
    always
d.orig.delays = fl.orig.delay(this.flight)  '' accumulate stats for day
s.orig.delays = d.orig.delays

wait fl.orig.delay(this.flight) days
fl.act.dep(this.flight) = frac.f(time.v)

fl.total.delay(this.flight) = fl.act.dep(this.flight)-fl.skd.dep(this.flight)

    if fl.total.delay(this.flight) >= (1/minutes.v/hours.v)
        d.all.delays = fl.total.delay(this.flight)
        s.all.delays = d.all.delays
    always

    if fl.total.delay(this.flight) >= (15/minutes.v/hours.v)
        d.serious.delays = fl.total.delay(this.flight)
        s.serious.delays = d.serious.delays
    always

'' determine total block hours

wait fl.blk.time(this.flight) days
    d.blk.time = fl.blk.time(this.flight)
    s.blk.time = d.blk.time

'' determine ac block hours

add fl.blk.time(this.flight) to ac.blk.hrs(this.aircraft)
```

```

fl.act.arr(this.flight) = frac.f(time.v)

'' logic for ground time
''if fl.act.arr(this.flight) = fl.skd.arr(this.flight)
''    wait max.ground.time minutes
'' else
''    wait min.ground.time minutes
''always

ac.location(this.aircraft) = fl.dest(this.flight)
ac.status(this.aircraft) = "NOT.ASSIGNED"
ac.fl.id(this.aircraft) = 99
call flight.report giving this.flight
''remove this.flight from fl.queue

END '' skedule

ROUTINE Flight.report given .fl

define .fl as a pointer variable

    define hours as an integer variable
    define minutes as a real variable

''    print 2 lines thus
''          FLT BLK  --SKEDULE--  --ACTUAL---  ----DELAYS----
'' ORIG DEST NUM TIME AC DEP ARR AC DEP ARR ORIG REACT ALL

    let hours = TRUNC.F(fl.act.dep(.fl) * hours.v)
    let minutes = fl.act.dep(.fl)*hours.v - hours
    let fl.ad(.fl) = hours*100 + minutes*minutes.v

    let hours = TRUNC.F(fl.act.arr(.fl) * hours.v)
    let minutes = fl.act.arr(.fl)*hours.v - hours
    let fl.aa(.fl) = hours*100 + minutes*minutes.v

    let hours = TRUNC.F(fl.orig.delay(.fl) * hours.v)
    let minutes = fl.orig.delay(.fl)*hours.v - hours
    let fl.o.d(.fl) = hours*100 + minutes*minutes.v

    let hours = TRUNC.F(fl.react.delay(.fl) * hours.v)
    let minutes = fl.react.delay(.fl)*hours.v - hours
    let fl.r.d(.fl) = hours*100 + minutes*minutes.v

    let fl.total.delay(.fl) = fl.orig.delay(.fl)+fl.react.delay(.fl)

    let hours = TRUNC.F(fl.total.delay(.fl) * hours.v)
    let minutes = fl.total.delay(.fl)*hours.v - hours
    let fl.t.d(.fl) = hours*100 + minutes*minutes.v

    print 1 line with fl.orign(.fl),
                    fl.dest(.fl),

```

```

        fl.id(.fl),
        fl.bt(.fl),
        fl.ac.plan.id(.fl),
        fl.sd(.fl),
        fl.sa(.fl),
        fl.ac.act.id(.fl),
        fl.ad(.fl),
        fl.aa(.fl),
        fl.o.d(.fl),
        fl.r.d(.fl),
        fl.t.d(.fl),
        fl.ac.arr.del(.fl)*hours.v

    thus
***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***   ***
END '' flight.report

```

ROUTINE DAY.PERFORMANCE.REPORT

```

define day.otp,day.otps as a real variable
define day.blk.hours as a real variable

```

```

day.otp = (no.of.flights-day.delays)/no.of.flights * 100
day.blk.hours = day.blk.time * hours.v

```

```

print 27 lines with no.of.aircraft,
                    no.of.flights,
                    day.blk.hours,
                    mean.del.time,
                    day.delays,
                    day.orig.time.delay*hours.v,
                    day.act.time.delay*hours.v,
                    day.all.time.delay*hours.v,
                    day.min.all.delay*hours.v,
                    day.max.all.delay*hours.v,
                    day.avg.all.delay*hours.v,
                    day.otp

```

```

thus

```

DAILY PERFORMANCE SUMMARY REPORT

A) OPERATING STATS :

FLEET	= **	AIRCRAFT
TOTAL DEPARTURES	= ****	FLIGHTS
TOTAL BLK HRS	= ****. **	HOURS

B) DELAY FUNCTION PARAMETERS :

MEAN DELAY TIME	= **. ****	HOURS
STANDARD DEV	= 1.0724	HOURS

C) PUNCTUALITY STATS FOR ALL DELAYS (> 0 min) :

TOTAL DELAYS	= ****	DELAYS
TOTAL DELAY TIME :		
ORIGINAL DELAYS	= ***. **	HOURS

```

        REACTION DELAYS = ***.**      HOURS
    ALL DELAYS           = ***.**      HOURS

    MIN DELAY TIME      = **.**        HOURS
    MAX DELAY TIME      = **.**        HOURS
    AVR DELAY TIME      = **.**        HOURS

    PUNCTUALITY PERFORMANCE ( > 0 min ) = **.**      %

day.otp = (no.of.flights-day.serious.delays)/no.of.flights * 100

    print 11 lines with day.serious.delays,
        day.serious.time.delay*hours.v,
        day.min.serious.delay*hours.v,
        day.max.serious.delay*hours.v,
        day.avg.serious.delay*hours.v,
        day.otp

    thus
D) PUNCTUALITY STATS FOR ALL DELAYS ( > 15 mins ) :

        TOTAL DELAYS      = ****      DELAYS
        TOTAL DELAY TIMES = ***.**      HOURS

        MIN DELAY TIME    = **.**        HOURS
        MAX DELAY TIME    = **.**        HOURS
        AVR DELAY TIME    = **.**        HOURS

    PUNCTUALITY PERFORMANCE ( > 15 mins ) = **.**      %

    print 1 line thus
        END OF DAY PERFORMANCE SUMMARY REPORT
    start new page

END '' DAY.PERFORMANCE.REPORT

ROUTINE AIRCRAFT.REPORT

Define .ac as a pointer variable

print 1 line thus
    DAILY AIRCRAFT UTILIZATION REPORT

for every .ac in ac.idle
do
    print 1 line with
        ac.id(.ac),
        ac.blk.hrs(.ac)*hours.v,
        ac.code(.ac)
    thus
        ****      *****.** hrs      *****
loop
print 1 line thus
    END OF AIRCRAFT REPORT

```

END 'end aircraft.report

ROUTINE SKD.PERFORMANCE.REPORT

define skd.otp,skd.otps as a real variable
define skd.blk.hours as a real variable
define all.delay.rate as a real variable
define serious.delay.rate as a real variable

skd.otp = (skd.depatures-skd.delays)/skd.depatures * 100
skd.blk.hours = skd.blk.time * hours.v

print 27 lines with no.of.aircraft,
skd.depatures,
skd.blk.hours,
mean.del.time,
skd.delays,
skd.orig.time.delay*hours.v,
skd.act.time.delay*hours.v,
skd.all.time.delay*hours.v,
skd.min.all.delay*hours.v,
skd.max.all.delay*hours.v,
skd.avg.all.delay*hours.v,
skd.otp

thus

SCHEDULE PERFORMANCE SUMMARY REPORT

A) OPERATING STATS :

FLEET	= **	AIRCRAFT
TOTAL DEPARTURES	= ****	FLIGHTS
TOTAL BLK HRS	= ****.**	HOURS

B) DELAY FUNCTION PARAMETERS :

MEAN DELAY TIME	= **.****	HOURS
STANDARD DEV	= 1.0724	HOURS

C) PUNCTUALITY STATS FOR ALL DELAYS (> 0 min) :

TOTAL DELAYS	= ****	DELAYS
TOTAL DELAY TIME :		
ORIGINAL DELAYS	= **.*	HOURS
REACTION DELAYS	= **.*	HOURS
ALL DELAYS	= **.*	HOURS
MIN DELAY TIME	= **.*	HOURS
MAX DELAY TIME	= **.*	HOURS
AVR DELAY TIME	= **.*	HOURS

PUNCTUALITY PERFORMANCE (> 0 min) = **.* %

skd.otps = (skd.depatures-skd.serious.delays)/skd.depatures * 100

print 11 lines with skd.serious.delays,

```

skd.serious.time.delay*hours.v,
skd.min.serious.delay*hours.v,
skd.max.serious.delay*hours.v,
skd.avg.serious.delay*hours.v,
skd.otp

```

thus

D) PUNCTUALITY STATS FOR ALL DELAYS (> 15 mins) :

```

TOTAL DELAYS      = ****      DELAYS
TOTAL DELAY TIMES = ***.**    HOURS

MIN DELAY TIME    = **.**      HOURS
MAX DELAY TIME    = **.**      HOURS
AVR DELAY TIME    = **.**      HOURS

```

PUNCTUALITY PERFORMANCE (> 15 mins) = **.** %

```

let all.delay.rate = (skd.all.time.delay*hours.v)/end.time
let serious.delay.rate = (skd.serious.time.delay*hours.v)/end.time

```

print 9 lines with MDAS,

```

max.ground.time, 'plan ground time
end.time,
all.delay.rate,
serious.delay.rate
thus

```

E) SKDMOD SUMMARY :

```

M D A S      = **.**      HOURS
PLAN GROUND TIME (SKD) = ***.**    MINS
SIMULATION PERIOD      = ***      DAYS
AVR DELAY TIME / DAY :
    ALL DELAYS      = ***.**    HOURS
    SERIOUS DELAYS  = ***.**    HOURS

```

print 1 line thus

END OF SKD PERFORMANCE SUMMARY REPORT

END '' SKD.PERFORMANCE.REPORT